GEOLOGY OF THE Elgin DISTRICT

95 (SCOTLAND) ELGIN

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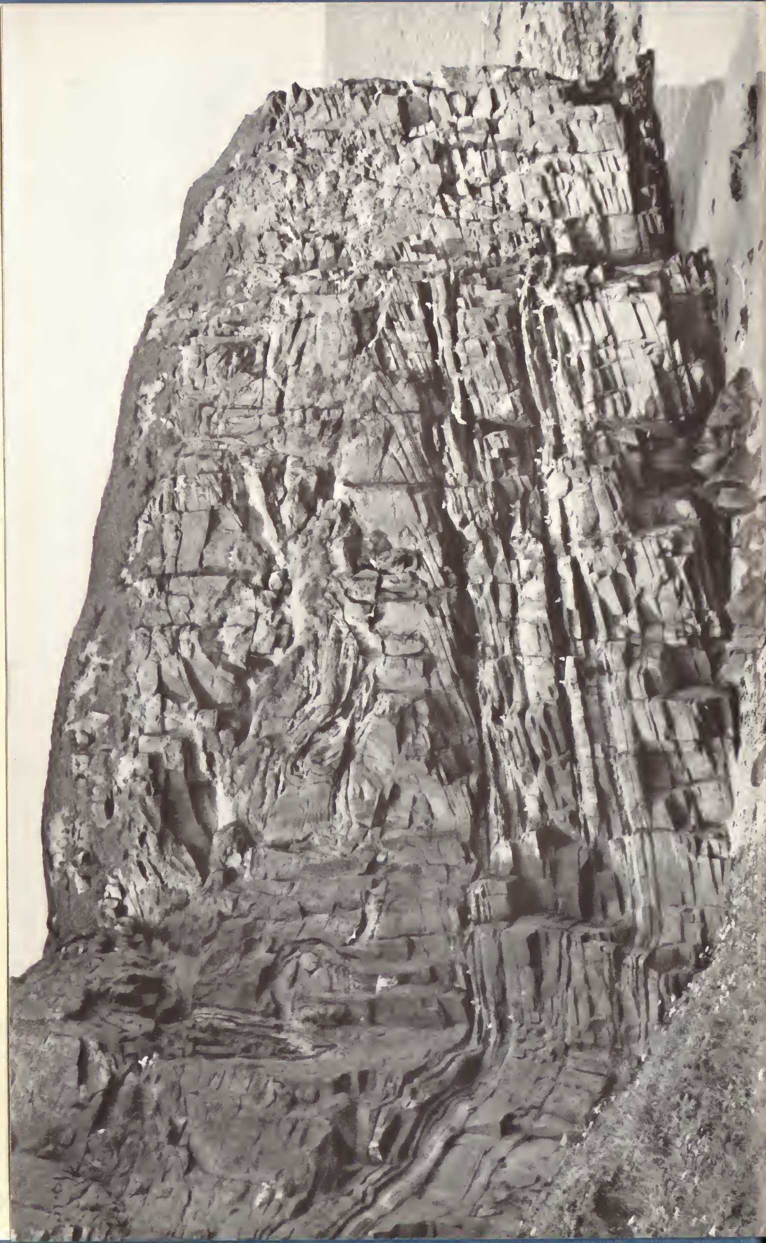
Scotland

PLATE I (FRONTISPIECE)

HOPEMAN SANDSTONE AT COVESEA QUARRY [16907035]

Contorted bedding in sandstone above normal dune-bedded sandstone. Height of cliff approximately 100 ft (D686).



NATURAL ENVIRONMENT RESEARCH COUNCIL
Institute of Geological Sciences

MEMOIRS OF THE GEOLOGICAL SURVEY
SCOTLAND

The Geology of the Elgin District

(Explanation of One-inch Geological Sheet 95)

By

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The Institute of Geological Sciences was formed by the incorporation of the Geological Survey of Great Britain and the Museum of Practical Geology with Overseas Geological Surveys and is a constituent body of the Natural Environment Research Council.

PREFACE

THE ORIGINAL one-inch geological Elgin (95) Sheet was a hand-coloured map published in 1886 as the result of a six-inch survey by J. S. Grant Wilson and James Linn. The area described in the following pages was resurveyed on the 6-inch to the mile scale between 1961 and 1963 by Drs. N. G. Berridge, A. L. Harris, F. May, and J. D. Peacock with Mr. T. R. M. Lawrie as District Geologist. Geophysical surveys were carried out by a team led by Mr. P. J. Fenning in 1963, and additional geological information was obtained from five shallow boreholes drilled during 1964 and 1965. The petrographical detail embodied in the memoir is largely the work of Drs. Harris, May and Peacock, but Mr. R. W. Elliot has contributed a note on the andesite of the Gollachy Burn. The spores from the Lossiemouth Borehole were identified by Dr. W. G. Chaloner, the ammonites by Professor D. T. Donovan, the ostracods by Dr. F. W. Anderson, and the remaining faunas from the bore by Dr. H. C. Ivimey-Cook. Other palaeontological determinations were made and assistance given by Dr. E. I. White, F.R.S., and Dr. R. Miles (Old Red Sandstone fish), by Dr. A. D. Walker (Permo-Triassic reptiles), by Messrs. A. R. Waterston and D. K. Kevan (Recent freshwater mollusca), by Dr. J. R. Haynes (Pleistocene foraminifera), and by Dr. R. C. Whatley (Pleistocene ostracoda). A chemical analysis of the Gollachy Burn andesite was carried out by Messrs. J. M. Nunan and G. A. Sergeant.

The memoir was written by Dr. Peacock with the exception of Chapter II (Dr. Harris), Chapter III (Dr. May), Chapter VII (Dr. N. G. Berridge) and Chapter VIII (Mr. Elliot and Dr. May). Mr. P. J. Fenning wrote the account of the geophysical investigations, and Mr. P. J. Brand compiled the fossil lists in the appendices. The memoir was edited by Dr. G. H. Mitchell.

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National Grid references are given in square brackets; all relate to the National Grid Square NJ. Figures in round brackets refer to the Scottish Sliced Rock Collection of the Geological Survey, e.g. (48136).

The Munsell notation is used for certain colour indices: it is shown in round brackets by a combination of figures and letters, e.g. pale brown (5 YR 5/2).

ILLUSTRATIONS

TEXT FIGURES

PLATES

LIST OF SIX-INCH MAPS

Geological six-inch maps included wholly or partly within the Elgin District are listed below with the initials of the surveyors and the dates of the revision survey. The surveyors were N. G. Berridge, A. L. Harris, F. May, and J. D. Peacock. The completed maps, which are National Grid sheets, are deposited at the Institute of Geological Sciences, 19 Grange Terrace, Edinburgh 9, where they are available for public reference.

NJ			NJ		
05 NE(N)	A.L.H.	1961–3	26 NW	J.D.P.	1961–2
06 SE	A.L.H.	1961–3	26 NE	J.D.P.	1963
15 NW(N)	A.L.H.	1963	27 SW(S)	J.D.P.	1961
15 NE(N)	A.L.H.	1962–3	35 NW(N)	F.M.	1963
16 NW	J.D.P.	1961–2	35 NE(N)	F.M.	1961–3
16 NE	J.D.P.	1961–2	36 SW	N.G.B.	1961
16 SW	A.L.H.	1961–2	36 SE	F.M.	1962–3
16 SE	A.L.H.	1962–3	36 NW(S)	J.D.P.	1963
17 SE(S)	J.D.P.	1961	36 NE(S)	F.M.	1963
25 NW(N)	N.G.B.	1962–3	45 NW(N)	F.M.	1961
25 NE(N)	N.G.B.	1961–2	46 NW(S)	F.M.	1961–2
26 SW	N.G.B.	1962–3	46 SW	F.M.	1961–2
26 SE	N.G.B.	1961–3			

Chapter I

INTRODUCTION

Location and Area

THE REGION described in the following account comprises the coastal parts of Morayshire and Banffshire between Kinloss and Portessie, an area of some 130 square miles (Fig. 1). The southern margin of the sheet extends from just east of Forres to Fochabers and the high ground of Aultmore. This district, which for convenience is termed the Elgin District, includes some of the richest agricultural land in Scotland, and, with its low rainfall and relatively open winters, is favoured in comparison with the country to the east and south.

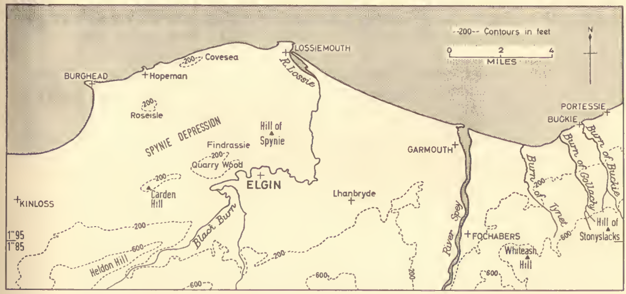

FIG. 1. *Sketch map of the Elgin district and the country to the south*

Physical Features

Morphologically the Elgin District falls into two parts divided by the valley of the River Spey. In the east the highest ground in the area, the Hill of Stonyslacks (955 ft O.D.) overlooks the western end of the till-covered platform of lower Banffshire (about 150 ft O.D.), which is underlain by Dalradian flags and quartzites and by sandstones and conglomerates of Middle Old Red Sandstone age.

West of the Spey the dominant features of the topography are the east-north-east trending ridges and valleys. In the north the Roseisle–Covesea ridge, formed mainly of New Red Sandstone rocks, is a low but prominent feature, the highest point of which reaches about 240 ft O.D. On the north side of the ridge are traces of terraces at about 120 ft O.D. near Burghead and 90 ft O.D. at Hopeman which may be remnants of a 'pre-Glacial' raised beach such as that described by Bremner at Stonehaven (1925, p. 40). To the east of the ridge stands the isolated hill of resistant Upper Triassic sandstone occupied by the suburbs of Lossiemouth, and to the south lies the drift-filled Spynie depression which merges into the lower Lossie basin. The Spynie depression, which may at one time have carried the River Findhorn and follows an important fault, has probably been much modified by the passage of ice during the Pleistocene. Between the Spynie depression and Elgin another east-north-easterly ridge extends from Carden Hill to Quarry Wood (a little over 400 ft O.D.) and the Hill of Spynie, beyond which it sinks below the Lossie alluvium. This ridge is built of resistant rocks of Upper Old Red Sandstone and Permo-Triassic age. On the southern margin of the map the Moine granulites of Heldon Hill, bounded to the south by a partially exhumed fault-scarp, reach over 750 ft. O.D., but fall eastwards to disappear below the Lossie alluvium south of Elgin. The cornstones within the Upper Old Red Sandstone give rise to a small low ridge immediately south of New Elgin.

The country in the Elgin neighbourhood is traversed by only two streams of any importance, these being the River Lossie and the Black Burn. The course of the former from where it enters the area was evidently considerably influenced by the events at the close of the Pleistocene, much of the ground being swathed in glacial sand and gravel. Farther east the River Spey occupies a well-defined valley flanked by gravel terraces cut in late-Glacial and post-Glacial times. East of the Spey the small but active burns of Tynet, Gollachy and Buckie flow through steep-sided valleys which are in places cut through the till into solid rock. The incision of the meanders in the courses of these streams was probably initiated as the sea began to fall from the high levels of late-Glacial times.

Superimposed on the two morphological divisions mentioned above are the features associated with the retreat of the Pleistocene ice and the late-Glacial and post-Glacial changes in sea-level. To the former may be attributed the contrast between the smooth, till-covered slopes of the ground east of the Spey and the hummocky sand and gravel characteristic of much of the country westwards from Buckie. The variations in sea-level, together with the redistribution by the sea of part of the immense deposits of sand and gravel left by the ice, are responsible for the spectacular storm beaches found on the coast between Portgordon and Lossiemouth, and farther west between Burghead and Kinloss.

History of Research

The geology of the Elgin District attracted considerable attention from the early Nineteenth Century onwards, and observations pertaining to the geology can be found in volumes I–IV of the Statistical Account of Scotland issued between 1792 and 1795. A geological map was published by Martin (1837) and more comprehensive treatments of the geology by Duff (1842) and Gordon (1859). The area was geologically surveyed by J. Linn and G. S. Grant Wilson of the Geological Survey between 1877 and 1881, and a map was published on the one-inch to one-mile scale in 1886.

During the middle part of the Nineteenth Century the accounts are mainly concerned with the strata bearing Old Red Sandstone fish and with the relations of these to the similar, apparently conformable rocks which began to yield a series of hitherto unknown reptiles from 1844 onwards (e.g. Gordon 1859; Murchison 1859; Harkness 1864; Judd 1873). The Old Red Sandstone was described by, among others, Murchison (1859) and Malcolmson (1859). A little earlier Jurassic strata were discovered at Linksfield, near Elgin (Gordon 1832), and these together with frequent occurrences elsewhere in Morayshire (Duff 1842) were later realized to be erratic blocks (Judd 1873) and part and parcel of the east and south-eastward dispersal of erratics into this and neighbouring areas (Cumming 1850; Martin 1856).

Later in the Nineteenth Century the discoveries of reptiles in the New Red Sandstone became frequent (e.g. Judd 1885; Huxley 1877; Newton 1893, 1894). Newton recognized the occurrence of two different faunas in these rocks and the possibility that one of these could be of Permian age (Wallace 1901, p. 138), and this hypothesis was put on a sound footing in the next two decades (Watson 1909; Watson and Hickling 1914) when the faunas were found to compare closely with those known from uppermost Permian and Middle Triassic rocks elsewhere.

Concurrently with the advances in the understanding of the New Red Sandstone, it was shown that the Old Red Sandstone south of the Moray Firth comprised the Upper and Middle divisions of that system and that the former could be subdivided on the basis of the fossil fish (Traquair *in* Harvie-Brown and Buckley 1896 and *in* Hinxman and Grant Wilson 1902; Taylor 1900; Horne 1923). More recently it has been suggested that the number of subdivisions in the Upper Old Red Sandstone can be increased to five, of which three occur within the Elgin District (Westoll 1951; Tarlo 1961).

In the field of sedimentary petrology a series of papers by Mackie between 1897 and 1927 on the cements, heavy mineral assemblages, and chemical composition of the Elgin sandstones and associated rocks were pioneer studies. He was able to show the lithological distinctness of the Triassic rocks and the resemblance of the coastal Hopeman sandstone to the Cutties Hillock (Quarry Wood) sandstone (1925), and recognized wind-faceted pebbles at the base of the latter (1901).

Following on the early work on the erratics in the superficial deposits, Mackie (1901) showed that there were several distinct boulder streams, and Bremner (1916, 1928, 1934) and Read (1923) put forward evidence of multiple glaciation in Morayshire and Banffshire to account for this and other phenomena, such as superimposed tills of differing lithology.

Summary of Geology

The following is a tabular statement of the geological formations of the Elgin District:

SUPERFICIAL DEPOSITS (DRIFT)

Recent and Pleistocene

Peat

River and lake alluvium

Present, post-Glacial, late-Glacial and storm beach deposits, and associated marine and estuarine alluvium

Glacial and fluvio-glacial sand and gravel

Glacio-lacustrine silt and clay

Till

SOLID FORMATIONS

JURASSIC

LOWER LIASSIC:	Sandstones, siltstones, mudstones and shales passing downwards into cementstone and greenish marl

PERMIAN AND TRIASSIC

UPPER TRIASSIC:	Cherty Rock (chert and limestone) Sandstones of Spynie, Lossiemouth and Findrassie
TRIASSIC:	Burghead Beds (mainly pebbly sandstone)
UPPER PERMIAN TO LOWER TRIASSIC:	Sandstones of Cutties Hillock (Quarry Wood) and Hopeman

OLD RED SANDSTONE

UPPER:	Rosebrae Beds (sandstones) Cornstone Beds (calcareous sandstone and limestone) Scaat Craig Beds (mainly pebbly sandstone) Alves Beds (mainly pebbly sandstone), probably equivalent in part to Cornstone Beds and Scaat Craig Beds
MIDDLE:	Sandstone, conglomerate, nodule beds
MIDDLE OR LOWER:	Buckie Beds (breccia, limestone, sandstone)

METAMORPHIC ROCKS

DALRADIAN:	Cairnfield Actinolitic Flags Findlater Flags with quartzite West Sands Mica-Schist Cullen Quartzite
MOINIAN:	Psammitic granulite, quartzite, pelitic schist

IGNEOUS ROCKS

?INTRUSIVE:	Andesite of ?Lower Old Red Sandstone age
INTRUSIVE (associated with Caledonian Orogeny):	Post-orogenic spessartite Late-orogenic microdiorite

The superficial deposits are shown on a separate 'Drift' edition of the one-inch map. In the south-west of the Elgin District (Fig. 2) the Moinian rocks, which are poorly exposed, are contiguous with a large area of these rocks in the ground to the south, and in the east the Dalradian strata can be referred in part to the groups erected for the Banffshire coast by Read (1923). The Cairnfield Flags, however, a group of actinolitic and calcareous beds which appear to lie within the Findlater Flags, do not occur on the coast to the north-east. Their presence must therefore be due either to rapid facies change or, since they are lithologically similar to the Garron Point Actinolitic Schists which occur higher in the Banffshire succession, to a major tectonic structure.

Of the three minor intrusive sheets mapped within the Dalradian, one, a late-orogenic microdiorite, is a slightly metamorphosed representative of a suite widespread in the Moine Schists of Inverness-shire, and the other two are spessartites intruded after the metamorphism of the country rock.

The Middle Old Red Sandstone rests with great unconformity on the Dalradian and extends south-westwards from the coast east of the Spey as a broad belt to the southern boundary of the sheet. The succession comprises a thick basal conglomerate overlain by sandstone and conglomerate with subordinate shaly seams and nodule beds, the last with fossils at some localities. On the coast at Buckie the basal conglomerate unconformably overlies a few feet of breccia and calcareous and arenaceous strata, the Buckie Beds, which could belong to either the Middle or the Lower division of the Old Red Sandstone. There is evidence that the surface on which the Middle Old Red Sandstone rests is one of moderate relief, and it seems probable that the deposits are of continental origin and were laid down under dominantly fluviatile conditions. The Gollachy Burn andesite, formerly mapped by tbe Geological Survey as a lava flow within the Middle Old Red Sandstone, is now thought more likely to be an intrusive sheet truncated by the basal conglomerate.

The Upper Old Red Sandstone of the Elgin District is dominantly sandstone with pebbly beds and horizons of pellet conglomerate. Calcareous sandstone and cherty limestone (cornstone) become important near Elgin. Though apparently conformable on the Middle Old Red Sandstone, the lowest beds (the Nairn Sandstones) which occur farther west, appear to be absent in the Elgin District. During deposition there was probably movement on the Rothes Fault, which resulted in an attenuated succession west of Elgin, and tbe limestones and calcareous sandstones forming the Cornstone Beds are not represented west of the fault. Soutb-west of Elgin the Upper Old Red Sandstone oversteps the Middle Old Red to rest directly on the Moine Schists of Heldon Hill. The fault on Heldon Hiil also appears to have been active during Upper Old Red Sandstone times, allowing the accumulation of strata similar to tbe Rosebrae Beds on the south side. Like the Middle Old Red Sandstone, it seems that the Upper Old Red Sandstone is a continental deposit laid down under dominantly fluviatile (flood plain) conditions.

The Permian and Triassic strata comprise aeolian and water-laid sandstones varying in age from uppermost Permian to Upper Triassic. They are imperfectly exposed in two strips, the more northerly between Burghead and Lossiemouth and the other west and north of Elgin. Their inter-relations are difficult to determine owing to poor exposure, faulting and probable rapid lateral lithological variation, and if it were not for the presence of two units carrying reptilian fossils there would be little reason to differentiate them from parts of the Upper Old Red Sandstone. At the base of the succession are the aeolian Sandstones of Cutties Hillock (Quarry Wood) and Hopeman which rest with slight angular unconformity on the Upper Old Red Sandstone. Near Burghead these pass upwards into possibly fluviatile pebbly sandstones, tbe Burghead Beds. Both these groups appear to thin rapidly eastwards, and at Lossiemouth are probably represented by only a few feet of calcareous siltstone and pebbly sandstone lying conformably below the Upper Triassic Lossiemouth sandstone. The New Red Sandstone succession is capped by the Cherty Rock, a deposit analogous to the recent silcretes of Africa and Australia. Since the Cberty Rock passes downwards directly into Burghead Beds south of Hopeman it seems possible that tbe upper part of the Burghead Beds here may be coeval with the Lossiemouth sandstone.

Jurassic rocks of Sinemurian age were penetrated by a Geological Survey borehole on Lossiemouth Airfield and may also occur concealed by drift at

Findrassie and north of Spynie. Lithologically these beds show little affinity to the Jurassic strata of Sutherland but the ammonite faunas indicate close chronological correlation. The general geological setting suggests that there is little angular discordance between the Jurassic and the underlying Cherty Rock. A small mass of Jurassic strata seen on the foreshore at Stotfield (Lossiemouth) is probably a fragment caught up in a fault.

During the Pleistocene the Elgin District was subjected to several episodes of glaciation which have left the lower ground mantled by till and meltwater deposits. Though the relationships of the various drifts cannot be determined with certainty within the Elgin District itself, comparison with neighbouring areas suggests that there were at least two and perhaps as many as three advances of ice into the district from the west or north-west, the latest of which did not penetrate into the ground south-east of Fochabers, and that at some early stage the area was affected also by ice descending from the high ground to the south. The last glacial phase, termed the Elgin Oscillation, probably took place before or during the (local) late-Glacial rise in sea-level. As the sea fell from the highest levels the ice wasted away, though a remanié ice-cap seems to have survived for a time west and north of Elgin, and another small remnant north-east of Fochabers. In post-Glacial times the drift sheets on low ground near the coast were subjected to selective marine action, producing the large stretches of gravel storm-beaches which extend intermittently along the coast from Kinloss to east of the River Spey. The marine and freshwater silts and clays deposited in the shallows behind the protecting shingle barriers now form some of the most fertile agricultural land in the district.

Structure

After the Caledonian orogeny, which imposed the fold systems and possible nappe structures on the Dalradian and Moinian rocks, there is little evidence of earth-movements apart from faulting and local gentle flexuring. The rock groups post-dating the Dalradian are separated by non-sequences or low-angle unconformities. Thus the general structural picture of the Elgin District west of the Dalradian area is of gently northward-dipping strata which are repeated by a number of east-west faults with downthrow to the south, and broken further by the northward continuation of the Rothes Fault and the north-east trending Heldon Hill Fault south-west of Elgin (Fig. 2). The east-west faults are probably post-Liassic in age, but some of the others have a longer and more complex history. The lack of solid exposure in much of the district, however, means that the positioning of many of the faults is in some doubt, and in some areas, especially west of Elgin, the faults have been carried through unexposed ground to explain the relationships of various rock groups.

The best exposed of the east-west faults is seen on the coast between Burghead and Hopeman, and again at Lossiemouth, where it disappears seawards in a north-easterly direction. West of Lossiemouth it throws the Jurassic underlying the airfield against Upper Old Red Sandstone to the north. The sparse mineralization associated with this fault is mentioned on p. 126. Farther south another major east-west fault is inferred running through the Spynie depression, the western part being drawn on geophysical evidence (p. 143): it seems likely that this also throws Jurassic against Upper Old Red Sandstone north of Findrassie and Spynie. A third fault of this group is seen at the Tynet Burn fish locality (Fig. 10) and the possible continuation westwards may explain the apparent anomaly between the northward dip of the Middle Old Red Sandstone and the north-east trend of its outcrop. Minor east-west faults probably of similar age occur at a number of localities, e.g. at Burghead, and east of Portgordon. In several cases the south (downthrow) side has a lateral component towards the west.

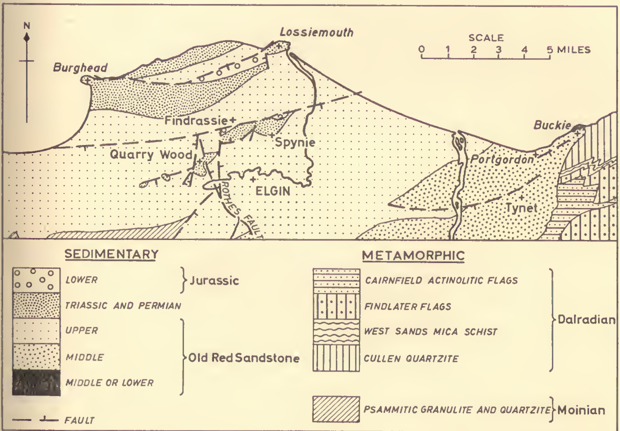

FIG. 2. *Sketch map showing distribution of principal rock groups and major faults in the Elgin district*

The Rothes Fault is nowhere exposed in the Elgin District but its continuation can be inferred from the northward shift of the Upper/Middle Old Red Sandstone boundary on the west side. Farther north near Elgin the thick Cornstone Beds of the Upper Old Red Sandstone east of the fault are not present west of it, and, as discussed on p. 45 there is evidence that the fault was moving during Upper Old Red Sandstone times, though most of the movement had apparently ceased before the deposition of the Rosebrae Beds. Further north a major fault passing between Quarry Wood and Findrassie may be a branch of the Rothes Fault system, reactivated at a later, post-Liassic date. This fault may be of the same age as the east-west faults described above. There is room for another branch of the Rothes Fault to pass west of Quarry Wood to Burghead Bay, but since the geological relations on the available evidence can be satisfactorily explained without it (see Chapter VI), it has been omitted from the 'Solid' geological map. The Heldon Hill Fault also seems to have been active during Upper Old Red Sandstone times, allowing the disposition of beds of Rosebrae lithology on the south side.

A group of north-trending faults of probably post-Liassic age bas been mapped in the Quarry Wood area, and another fault possibly with the same trend brings the Jurassic of Lossiemouth Airfield against tbe Upper Old Red Sandstone and Permo-Triassic strata to tbe east. Other small faults of varying ages are described in the field-details of succeeding chapters.

The joint pattern in the Permian and Triassic rocks in the north half of the sbeet shows a broad maximum between N. 80° E. and E. 35° S. with very subsidiary maxima at N. 15° E. and N. 55° E. The majority of the easterly or east-south-easterly joints at any one locality comprise two sets with a small angle between them. On the coast in particular there are many silicified shear-planes on which little displacement can be detected: these may be of much the same age as the east-west faults mentioned earlier. The coastal exposures of the Hopeman sandstone show sets of sub-horizontal joints at many localities, and it is possible that some of these may be due to stress relief perpendicular to the ground-surface before or during the formation of the present cliffs. J.D.P.

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Chapter II

MOINIAN

INTRODUCTION

THE MOINIAN rocks which crop out within the area of the Elgin (95) Sheet lie at the extreme northern edge of the extensive belt of metamorphic granulites which form much of the Central Highlands of Scotland. They pass northwards below the Middle Old Red Sandstone rocks which rest unconformably on a very irregular eroded surface cut in them. On the south-east side of Heldon Hill the Moinian rocks are separated from the Old Red Sandstone by a fault. The area of Moinian rocks occurring within the Elgin (95) Sheet is so small that mapping was extended southwards beyond the sheet margin, and the area described here is shown on the map (Fig. 3).

LITHOLOGY

The main rock-groups distinguished within the Moinian rocks of the area are indicated on the map (Fig. 3) by the letters A–C. Exposures are sparse, and consequently the lines separating the different rock-groups are for the most part conjectural, and relationships between the groups can be described only in the most general terms. Sedimentation structures were not recorded and consequently it is not possible to indicate the stratigraphical relations of the different lithological groups. Observation of the strike and dip of the foliation planes suggests that the generalized dip of the formations is towards the north with the result that Group A occupies the highest structural horizon and Group C the lowest. The different rock groups are described separately below.

Group A consists of rather feldspathic psammitic granulite, having in places stripes and bands of pelitic and semi-pelitic schist. One specimen of pelitic schist (48986) is unusual in that it has strongly folded thin stripes up to $\frac{1}{4}$ in across (Plate IIA) containing a very high proportion of apatite (up to 15 per cent). The apatite-rich stripes, which probably represent original bedding laminae, are more fine-grained than the remainder of the rock which consists of muscovite-biotite-schist with small anhedral garnets and small porphyroblasts of twinned albite.

Group B is mainly siliceous psammitic granulite and quartzite. In places the psammite is massive but more often exhibits a well-defined flaggy structure. It is well exposed in the crags [140582] 600 yd N.N.W. of Pluscarden Abbey and in the grounds of Burgie House [088595]. In thin section (48984) [140582] the flaggy quartzite exhibits a platy texture, the quartz grains being arranged in parallel-sided zones.

Group C is dominantly psammitic, although it contains mappable bands of pelitic schist. The group is well exposed in quarries at Wester Newforres [063578] and near the summit of Heldon Hill [137581]. The psammitic rocks vary from micaceous feldspathic psammite to quartzite. The more micaceous psammite occurs in the quarry near the summit of Heldon Hill, while the quartzite occurs as bands in normal quartzo-feldspathic granulite in the quarries at Wester Newforres. The psammite at the latter locality contains thin stripes and partings

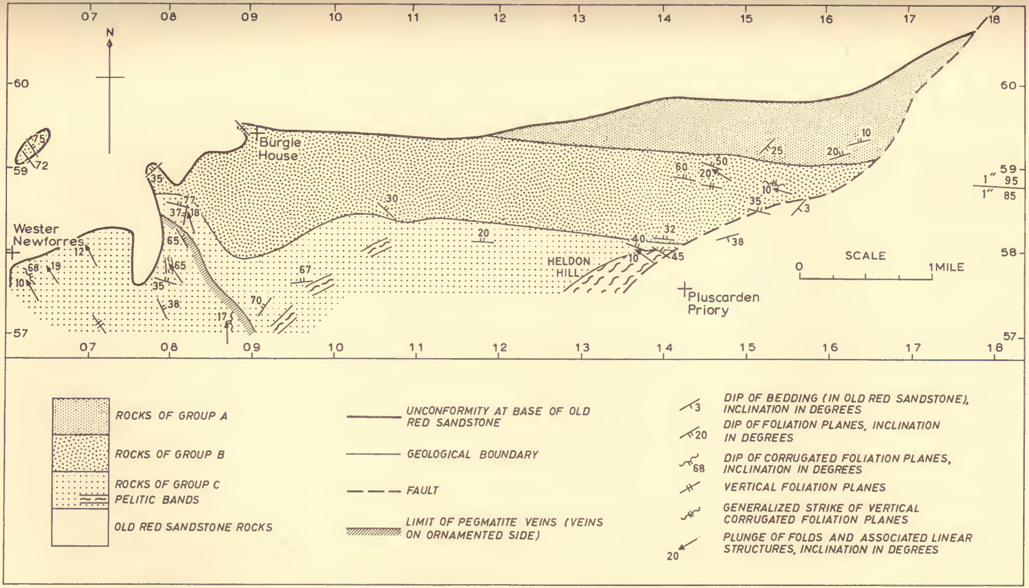


FIG. 3. *Subdivisions and structure of the Moinian rocks*

of pelitic schist. A band of hornblende-schist about 1 ft thick is present in the most easterly quarry at Wester Newforres. The hornblende-schist, which is concordant with the main planes of foliation in the psammite, exhibits a marked preferred crystallographic orientation of amphibole crystals (46983), many of which have been partially replaced by biotite; small patches of the hornblende-schist are rich in epidote and sphene.

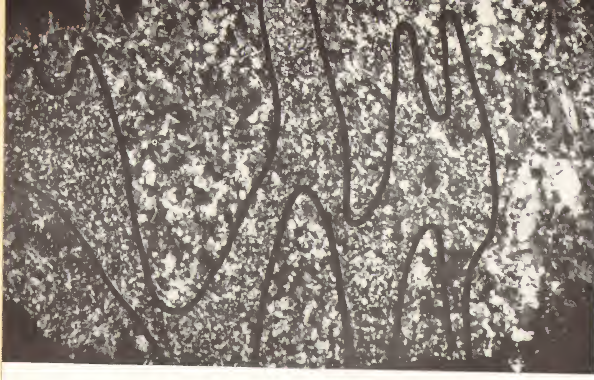
The foliation planes in the rocks of Group C are cross-cut by many veins of granite pegmatite which, in places, are up to 4 ft in thickness but which are normally 1 to 2 ft across. In hand-specimen the pegmatite largely consists of crystals of pink feldspar, up to 2 in in diameter, with interstitial white feldspar and quartz; there are often small scattered flakes of white mica and sparsely distributed large quartz segregations. At some localities near the margin of the veins, the pegmatite shows a rudimentary foliation, concordant with that in the country rock, and caused by the rough orientation of white mica. The pegmatite veins are confined to the south-west part of the area (Fig. 3), and have not been recorded on Heldon Hill.

In thin section the pegmatites are seen to consist very largely of microcline showing areas of vein perthite and containing small patches of myrmekite growing out from small lath-shaped plagioclase crystals adjacent to the micocline (46980). Quartz occurs mainly as granular aggregates. Isolated patches of the pegmatite are free from microcline (51587) and such patches consist almost entirely of quartz and plagioclase, with aggregates of zoisite needles, included within plagioclase crystals. In one or two cases (46982) zoisite occurs in veins cutting large crystals of microcline.

Locally, the pegmatites have been subjected to a strong deformation of brittle type. Such deformation has caused the fracturing and bending of twin lamellae in plagioclase and the disruption, partial or complete, of microcline phenocrysts. Those phenocrysts which are not fractured often show undulose extinction. In places the pegmatites are transected by zones of strong shear, characterized by a quartz fabric, often very fine-grained, in which individual grains are dimensionally orientated parallel to the shear planes, and by the patchy development of similarly orientated white mica. Deformation of the feldspar phenocrysts and the rare larger quartz crystals is more marked in the vicinity of the shear planes. Most of the fractures in the feldspar phenocrysts are filled with vein quartz.

Structure

The Moinian rocks of the area are characterized by planes of foliation. In the psammitic rocks the foliation is developed as a well-marked flaggy structure, although massive varieties occur. The pelitic rocks are characterized by a strong schistosity produced by a preferred orientation of micaceous minerals. The folding which produced the main planes of foliation was not observed. Since, however, the foliation planes lie at very low angles to planes of lithological banding, it may be assumed that the former lie parallel to the axial planes of folds which are nearly isoclinal in form. Slight colour-banding in some of the psammitic rocks probably indicates original bedding, while the contacts between pelitic and psammitic stripes especially in Groups A and C probably represent original bedding planes subsequently modified by deformation. One pelitic rock from Group A (48986) described above contains apatite-rich stripes which are probably original bedding laminae.



A

B

C

Many exposures exhibit no minor structures other than foliation, but in the quarries at Wester Newforres overturned and fairly tigbt folds and associated structures such as crumpling, mullions and rodding plunge at low angles towards the north-nortb-west. The axial planes of these folds dip at approximately 15 degrees towards the west (Plate IIB and IIC). Linear structures, probably associated with this episode of folding, plunge towards the north-north-west throughout the western part of the area, where the strike of the foliation planes has a similar trend. Towards the east, however, where the foliation changes its trend to lie nearly east-west, the lineations change in trend to plunge towards the west-nortb-west.

There is some evidence of considerable variation in the inclination of the foliation planes across the strike, although as mentioned above, the generalized dip of the Moinian formations is towards the north. The variation in the attitude of the planes may be the result of the development on a large scale of the tight overturned folds described above.

The change in the trend of the foliation planes from west to east suggests the presence of a major open fold, probably a synform, trending between south and soutb-west. Tbe observation that the tight folds and associated lineations change their trend with tbe change in the orientation of the foliation planes suggests that the linear structures pre-dated the formation of the open synform.

The tight folds and their associated linear structures fold, and therefore post-date, the main foliation planes in the pelitic and psammitic rocks so that it is possible to postulate the following sequence of structural events:

1. The formation of the main megascopic foliation planes, probably during a period of isoclinal folding.
2. The formation of tight overturned folds, with associated linear structures, on axes now varying from north-north-west to west-north-west in trend.
3. The formation of open fold structures on an axis trending approximately north-north-east.

Faulting which occurred after the episodes of folding is discussed elsewhere (p. 7).

The Moinian rocks have been regionally metamorphosed. The bighest grade reached by the progressive regional metamorphism is uncertain, but it was sufficiently high to cause the crystallization of garnet in the pelitic rocks of Group A and of amphibole in the hornblende-schist of Group C. Evidence of metasomatism derives from tbe presence of albite porphyroblasts in the pelite of Group A and from the fact that the pelitic schist mapped on Heldon Hill is heavily feldspathized. The partial replacement of amphibole by randomly orientated biotite indicates the development of retrogressive metamorphism under static conditions. A.L.H.

PLATE II

A. PHOTOMICROGRAPH SHOWING FOLDED FINE-GRAINED APATITE-RICH 'LAMINAE' IN MICA-SCHIST
Crossed nicols. Magnification × 5 (*MN(S)* 856)

B. OVERTURNED TIGHT FOLD OF FLAGGY PSAMMITIC ROCKS IN WESTER NEWFORRES NEW QUARRY (WEST SIDE) (D 716)

C. OVERTURNED TIGHT FOLDS OF SILICEOUS PSAMMITIC ROCKS AT THE TOP OF WESTER NEWFORRES OLD QUARRY (EAST SIDE) (D 715)

Chapter III

DALRADIAN

INTRODUCTION

DALRADIAN metasediments crop out over an area of 11 square miles in the extreme eastern part of the sheet. West of a line joining Buckie, Clochan and Braes Cairn the metamorphic rocks, which generally dip at about 25 degrees towards the south-east, are concealed beneath a cover of Old Red Sandstone rocks.

In the Dalradian four main subdivisions are recognized. Each has been traced from the east margin of the sheet westwards until it disappears beneath the Old Red Sandstone. Three of these subdivisions, the Cullen Quartzite, the West Sands Mica-Schist and the Findlater Flags have been shown to be the inland continuation of groups well known from the type Banffshire coast section (Read, 1923). The outcrop of the fourth subdivision, for which the name Cairnfield Actinolitic Flags is proposed, does not extend as far as the coast and its correlation with the type succession is uncertain. Cross-bedding in the Cullen Quartzite shows that it youngs towards the south-east and that it forms the lowest part of the succession. In the area under description the base of the Cullen Quartzite is hidden beneath the Old Red Sandstone but to the south near Rothes in the Rothes (85) Sheet, its equivalent, the Ben Aigan Quartzite, rests directly on Moine granulite.

The earliest description of the metamorphic rocks of Banffshire in which the Buckie district is mentioned was given in 1800 by Robert Jameson. Hay Cunningham's 'Geognostical Account of Banffshire' which was published in 1843 is accompanied by a map showing a twofold division of the schists south of Buckie which approximately corresponds to the Cullen Quartzite and the schists and flags to the south. Brief descriptions were also given by Harkness in 1862, by Jamieson in 1871, and by Wallace in 1880. The Geological Survey of Scotland one-inch to one mile Sheet 95 published in 1886 distinguishes areas of quartzite from hydro-mica schist and flags.

There has been no recent work dealing specifically with the Dalradian of the Elgin (95) Sheet, but several important works describing the ground lying immediately to the east may be mentioned. For a general description of the Banffshire coast section and the inland area to the south the reader is referred to the Geological Survey memoir dealing with the geology of sheets 86 and 96 (Read 1923). Various aspects of the stratigraphy, structure and metamorphism are described by Read (1936, 1955), Sutton and Watson (1956), and Johnson (1962).

CULLEN QUARTZITE

The Cullen Quartzite crops out over several square miles around Buckie and Rathven. The dip is everywhere to the south-south-east at an average inclination of 35 degrees. Between the Mucks [424665] where the lowest beds are exposed and Arradoul [422632] where the quartzite dips below the West Sands Mica-

Schist, the thickness is estimated to be at least 4500 ft. East of Arradoul structural complications have led to a widening of the outcrop.

The Cullen Quartzite is well exposed on the offshore skerries known as the Mucks and on the shore and in the raised beach cliff between Portessie and Buckie. Unfortunately the coast is parallel to the strike and as a result of this only a small thickness is exposed. Inland exposures are scarce. Half a mile of fairly continuous section occurs in the Burn of Buckie south of the town. The quartzite is also exposed at Hillocks [430637] and in a small disused quarry on Clean Hill [435637]. Very discontinuous exposures can be found in Freuchny Stripe [433657] and the Burn of Rathven [439658].

The Cullen Quartzite has closely similar characteristics throughout the area under description. It consists almost entirely of quartzite in beds from 1 to 3 ft in thickness. The quartzite is light-grey in colour with black streaks marking concentrations of heavy minerals. Cross-bedding, which is extremely abundant and well-preserved, is picked out by these black streaks. The cross-bedding shows that the quartzite is the right way up and younging to the south-east. Folds which are probably slump structures have been noted in a few places, notably on the shore immediately west of Cluny Harbour [426658] and in the raised beach cliff at Ianstown [438664]. Coarse gritty bands, in which clastic grains can be easily distinguished, are common although pebbles appear to be entirely absent.

In hand specimen the quartzite appears to be relatively little altered but in thin section (47074) it is seen to be thoroughly recrystallized and the sites of clastic quartz grains are only rarely seen (48136). It is composed of interlocking grains of quartz and potash feldspar, the feldspar sometimes making up as much as 25 per cent of the whole rock. Biotite, iron ore, garnet and zircon are concentrated in the black streaks. The zircons are particularly interesting as they are rounded and thus probably represent unmodified clastic grains.

Calcareous bands are fairly common between Bents Point [434664] and Little Hythe [421658]. They are a light pinkish grey in colour and characterized by abundant brown and black oval spots up to 5 mm across. In slice (48150) the mineral components are seen to be quartz and calcite with smaller amounts of clinozoisite and acid plagioclase. The accessory constituents include sphene and zircon. The brown spots are due to poikiloblastic garnets, probably grossularite. Aggregations of biotite flakes give rise to the black spots.

Thin bands of muscovite-bearing quartzite are very common throughout the Cullen Quartzite. In slice (47076) they are similar to the more massive varieties of quartzite except for the presence of abundant muscovite. The muscovite flakes have a well-developed parallel orientation which imparts a pronounced schistosity to the rock.

Bands of mica-schist up to three feet in thickness are fairly common. The schist is black in colour and many of the bands are studded with numerous pink garnets. A specimen (48135) from Peter Hythe is composed of muscovite, biotite and some quartz. The micas have an almost perfect parallel orientation.

West Sands Mica-Schist

The Cullen Quartzite is succeeded by the West Sands Mica-Schist which forms a narrow outcrop extending from the eastern edge of the sheet at Rochomie Reservoir [442631] westwards as far as Easter Bogs [413627] where it disappears below the Old Red Sandstone. It is made up of garnet-mica-schist with abundant psammitic ribs. In places siliceous rocks make up more than 50 per cent of the total. In the area of Sheet 95 the West Sands Mica-Schist is very poorly exposed and consequently it has not been possible to limit it accurately on the map. The thickness is probably not more than 500 ft.

The best exposure occurs in a gully [443636] close to the edge of the ground shown on the sheet. The main rock type here is a garnet-mica-schist. Siliceous ribs are very common but pure quartzite is absent. At the north-west end of the exposure a downward passage into micaceous quartzite probably marks the junction with the Cullen Quartzite. The West Sands Mica-Schist was formerly well exposed in a quarry [441632] near Rochomie Reservoir but it is now badly overgrown. Another very small exposure of grey siliceous flags with partings of garnet-mica-schist occurs at a locality [41606286] south-west of Arradoul Smithy.

In thin section (48125) a typical mica-schist is seen to be composed of muscovite and quartz with smaller amounts of garnet and biotite. The accessories include minute grains of greenish brown tourmaline, opaque ore, zircon and apatite. A schistosity, which is due to the preferred orientation of mica, lies parallel to a compositional layering which is picked out by sharp variations in the proportions of the principal minerals. The quartz grains are equidimensional with an average diameter of 0·2 mm. The schistosity curves round large garnets which are rounded or angular with signs of fracturing. They contain abundant inclusions of quartz lying in trails which are oblique to the schistosity in the groundmass. A striking feature of these inclusions is the fact that they have an average grain-size of only 0·03 mm which is very much less than the grain-size of the quartz in the groundmass. Although the garnets show unmistakable signs of post-crystalline deformation there is only very slight marginal alteration to chlorite.

Findlater Flags

The West Sands Mica-Schist passes upwards into a thick group of semipelitic flags which can be traced north-eastwards to the type section at Findlater Castle in the Banff (96) Sheet. They form practically all the high ground in the south-east corner of the sheet and much of the lower ground around Drybridge [435625]. The presence of the narrow strip between Arradoul Mains [422632] and the Old Red Sandstone is conjectural owing to a complete absence of exposures, and it is possible that here the Cairnfield Actinolitic Flags rest directly on the West Sands Mica-Schist.

A fairly continuous section occurs in the Core Burn between Linnhouse Wood [433619] and Newton of Letterfourie [438607]. Discontinuous exposures occur at localities in the Burn of Letterfourie [441621], in the Addie Burn [440600], in Ault Kittoch [438600] in White Stripe [430601], in the Allobane Burn [419596] and in the Ardmachie Burn [413590]. Good exposures also occur in the large disused Tarrymount Quarry [411585].

In the Drybridge area the bedding is inclined towards the south-south-east at an average of 20 degrees. This dip is maintained in the Minduff area [434603] but in the south-west around Tarrymount it is towards the east-south-east at an average of 25 degrees.

The Findlater Flags are mainly fissile fine-grained semipelitic rocks. They are various shades of grey in colour and bedding is picked out hy clean-cut colour variations giving the rock a regular finely laminated appearance. Ripple-lamination is sometimes seen. The original sediments were prohably silty sands with clayey partings. In slice (48146) the flags are composed of biotite, muscovite, quartz and acid plagioclase. Tourmaline is always a conspicuous accessory and garnet is present in some of the slices. The micas have a fairly well-developed parallel orientation giving rise to a schistosity which is usually suh-parallel to the bedding. The quartz grains, which are equidimensional, have an average diameter of approximately 0·06 mm. This is notably less than the grain-size of the West Sands Mica-Schist.

An exceptional band of flags capable of yielding slabs thin enough for roofing purposes is exposed in the disused Tarrymount Quarry [411585]. The fissile character of these flags is due to extremely regular hedding in which granular siliceous hands commonly much less than an inch thick are separated from one another by schistose partings rich in muscovite. Breakage takes place along the micaceous partings giving smooth silvery surfaces whicb are in places studded with small garnets. In section (47067–9) these flags are composed of quartz, acid plagioclase, muscovite, biotite and small amounts of garnet. The predominant mica is usually muscovite. The garnets have a very ragged outline and are full of inclusions of quartz which have ahout tbe same grain-size as the quartz in the groundmass.

Exposures of fissile muscovite-rich flags also occur in the Ardmachie Burn at a locality [413590] 300 yards upstream from the old railway hridge, in White Stripe at a locality [430600] 1000 yd S. of Birkenbush Hillpark and in the Core Burn at a locality [438603] 500 yd S. of Newton of Letterfourie. Each of these exposures is approximately along the strike from Tarrymount Quarry and it appears likely that they are all at approximately the same horizon within the Findlater Flags.

A band of quartzite ahout 120 ft thick occurs within the Findlater Flags. It enters the ground under description just east of the Hill of Stonyslacks where it is exposed near the path and in a small crag [438587]. It forms a conspicuous ridge littered with quartzite dehris running west from the Hill of Stonyslacks. West of Broken Moan [425586] it appears to be offset hy a north-west-trending fault. Beyond the fault it continues in a west-north-west direction, hut west of the road the outcrop swings round towards the south. Just east of the road brilliant white bedded quartzite dipping towards the south at 27 degrees is well exposed in a small disused quarry [41905867]. The thickness of individual heds within the quartzite varies from 1 in to 1 ft and they are separated from each other by very thin partings of white mica. Extremely weathered, thinly-hedded quartzite with pelitic hands is exposed in the more northerly of two small road-side excavations [41805875]. From its position it is clear that this exposure lies near the hase of the quartzite and it provides evidence of a passage through flaggy quartzite with pelitic hands downwards into normal Findlater Flags. No evidence bas been found to indicate the nature of the upper boundary of the quartzite.

East of Tarrymount Quarry a low north-south trending ridge with ahundant loose quartzite fragments marks the position of the quartzite.

In slice (47066, 47070) the quartzite is composed almost entirely of large interlocking grains of quartz. All traces of a clastic texture have been completely obliterated by recrystallization. A few small scattered flakes of muscovite occur but feldspar is absent. It differs petrograpbically from the Cullen Quartzite in the absence of feldspar and in the coarse grain size.

It is possible that the Stonyslacks quartzite is the same horizon as the quartzite at Findlater Castle in the Banff (96) Sheet.

Cairnfield Actinolitic Flags

The characteristic which distinguishes the Cairnfield Actinolitic Flags from the Findlater Flags is the presence of actinolitic flags containing pale calcareous ribs. Its stratigrapbical position is uncertain and will be discussed below (p. 20).

The Cairnfield Actinolitic Flags outcrop east and south of the village of Clochan [402608]. In the north the bedding dips towards the south-south-east at an average of 20 degrees. Farther south in the area between Oxhill [403598] and Braes Cairn [395583], the dip is towards the east-south-east at an average of 25 degrees. Fairly continuous sections are available in the Burn of Cairnfield and the Burn of Tynet. Good exposures also occur in the Ardmachie Burn and in disused quarries at Oran [413619], Cuttlebrae [404616] and Braes Cairn [396584].

The rocks of the Burn of Cairnfield are fine-grained, dark-grey to black, semipelitic flags with numerous amphibole-bearing bands. The amphibolitic horizons vary from a few inches to tens of feet in thickness. They are dark greenish grey in colour and in hand specimen appear to be very coarse-grained because of the abundance of large porphyroblasts of actinolite. The bedding is picked out by regular colour variations and by white calcareous ribs and micaceous partings. The schistosity is usually subparallel to the bedding but the Cairnfield Actinolitic Flags are in general less fissile than the Findlater Flags. In section (48143) the actinolitic rocks are composed of a fine-grained groundmass of biotite, quartz and calcite. Very pale green actinolite forms large randomly orientated porphyroblasts. The porphyroblasts bave a subhedral to ragged form and are sieved witb inclusions of quartz. The inclusions have the same grain-size as the groundmass and they are sometimes arranged in trails which show that the bedding passes undisturbed through the porphyroblasts. The actinolite is sometimes decomposed into a semi-opaque material (48142). The biotite is a very pale-coloured variety which probably approaches pblogopite in composition. It has a well-marked parallel orientation giving rise to a schistosity. Epidote is commonly present. Scapolite has been recorded in one section (48141) where it occurs in slightly discordant veinlets composed of quartz, biotite, calcite and epidote. It forms anhedral grains which are partly or completely altered to a pale greenish brown slightly pleochroic substance. Chlorite in the form of fairly large flakes cutting across the schistosity is present at some localities (48145).

The amphibole-bearing flags exposed in the Burn of Auchiefow [405600], in the Ardmachie Burn [405594] and in the Burn of Tynet [402590] have a different texture. Instead of building stout disorientated porphyroblasts the actinolite occurs as needles wbich tend to lie parallel to the schistosity (47058–9, 47065, 48295). In other respects they are similar to the flags from the Cairnfield area.

Calcareous ribs are frequent througbout tbe Cairnfield Actinolitic Flags. They are particularly abundant in Cuttlebrae Quarry [404616] and the Howe of Tarwathie [407617] where they locally make up about 25 per cent of the rock.

In the last-named locality they are up to 6 in thick but usually the thickness is less than 1 in. In slice (47055, 47064) the calcareous ribs are composed of calcite and quartz with a little white mica. The quartz grains are equidimensional but the calcite crystals sometimes show a marked elongation parallel to the schistosity. Biotite-calcite-schist is associated with the calcareous ribs in places (47055). The mica, which is very pale in colour, is probably phlogopitic biotite. Grey calcareous flags with small white oval spots have been noted at a number of localities in the Howe of Tarwathie and the Burn of Cairnfield. In section (48129) they are seen to be composed of biotite, calcite, quartz, muscovite and epidote. The spots consist of equidimensional grains of quartz, calcite and a brown, slightly pleochroic, substance which is probably an alteration product although the identity of the parent mineral is problematical. The grain size within the spots is slightly greater than that of the matrix and each spot is surrounded by a thin selvedge rich in biotite. The light colour is due to the scarcity of biotite compared with the amount present in the matrix.

The rock exposed in the quarry [396584] on Braes Cairn is an epidote-muscovite-biotite-schist. In hand specimen the rock is light grey in colour with small pale spots. In section (47061) the epidote is seen to occur as abundant evenly distributed crystals which appear to be randomly orientated. The crystals have semi-opaque cores surrounded by clear colourless rims. The extinction angle of the cores is different from that of the rims. The spots are about 3 mm in length and are composed of muscovite with a small amount of quartz. Very small quantities of ore, epidote, biotite and tourmaline also occur. A thin dark skin rich in biotite surrounds each spot. The origin of the spots is obscure.

Kyanite and staurolite are found at some localities in pelitic and semipelitic rocks of the Cairnfield Actinolitic Flags but not in the amphibole-bearing or calcareous rocks. Large crystals of kyanite associated with concordant lenses of quartz occur at the following localities: (1) Burn of Cairnfield—several localities between [420614] and [42116128], (2) Burn of Cairnfield [42146072], (3) Core Burn [43786096]. The quartz lenses which occur in a fine-grained host rock contain a small amount of pink feldspar and well-scattered blades of kyanite. The kyanites are colour-zoned, the cores being a deep sapphire blue and the rims pale blue. The largest crystals are approximately 5 cm long, 1 cm wide and 3 mm thick. In section (48131) the lenses are seen to be composed of large interlocking grains of quartz with a little partly chloritized biotite. The kyanite shows marginal alteration to white mica. The lenses are surrounded by a coarse-grained micaceous selvedge up to 1 cm thick. A section (48130) through a selvedge shows quartz, partly chloritized biotite, and porphyroblasts of kyanite and staurolite. Inclusions of elongated ore grains show that the schistosity passes undisturbed through the porphyroblasts.

Kyanite and staurolite are not invariably associated with quartz segregations. For example in the Burn of Cairnfield near the junction with Forklands Stripe [42156087] bluish spots in micaceous flags are seen in section (48144) to be due to skeletal porphyroblasts of kyanite crammed with inclusions of quartz. A thick band of mica-schist (48127) exposed in the Burn of Auchiefow at Oxhill [407598] contains porphyroblasts of staurolite which are partly altered to chlorite. Biotite forms flakes lying parallel to the schistosity and also large porphyroblasts whicb cut across the schistosity.

In their pre-metamorphic condition the sediments of the Cairnfield Flags were probably dolomitic silts with ribs of limestone, interbedded with non-dolomitic silts and shales. The Cairnfield Flags are in general very similar to the Garron Point Actinolitic Schists while some of the calcareous and the kyanite- and staurolite-bearing rocks resemble rocks in the Crathie Point Calcareous Group of the Banff (96) Sheet. It is possible that the Cairnfield Actinolitic Flags merely represent a facies variation within the Findlater Flags but it is more probable that they are equivalent to the Crathie Point and Garron Point groups. If this correlation is accepted then it follows that the present anomalous position of the group is the result of a major tectonic structure (p. 25).

Structure

Minor structures

Small-scale tectonic structures are well-developed in the Findlater and the Cairnfield Actinolitic Flags but in the Cullen Quartzite they are very imperfectly developed and often difficult to measure. From the limited evidence available it is clear that the minor structures reflect several periods of movement.

The earliest structure, a schistosity lying parallel to the bedding, has been recognized at only two localities. Elsewhere it appears to have been completely obliterated by the superimposition of a later schistosity. The early schistosity is probably related to a period of folding which for convenience of description will be called F1.

Fig. 4. *Sketch of vertical section exposed on the north-east side of the Linn of Cairnfield* [416619]. *Minor folds* (*F2*) *in actinolitic flags. Note axial plane cleavage and in the north-west end of the section a small monocline* (*F4*)

Almost all the minor folds that have been found appear to belong to a single period of folding (F2). Small folds are well seen in the Core Burn and the Burn of Tynet but the best examples occur at the Linn of Cairnfield beside the path leading to the dam [416619] (Fig. 4). The axes and axial planes show only a slight regional variation of orientation in the area under description (Fig. 5). Over most of the Cairnfield–Findlater Flags outcrop the axial planes dip towards the south-east at an average of 25 degrees. The axes plunge towards the south-west at angles varying from 0 to 20 degrees. In the Burn of Tynet area the axial planes dip towards the east-south-east at an average of about 30 degrees while the axes plunge north-east at angles varying from 0 to 20 degrees. The axial planes are usually more steeply inclined than the general dip of the bedding although the reverse relationship is, of course, found on the overturned limbs of

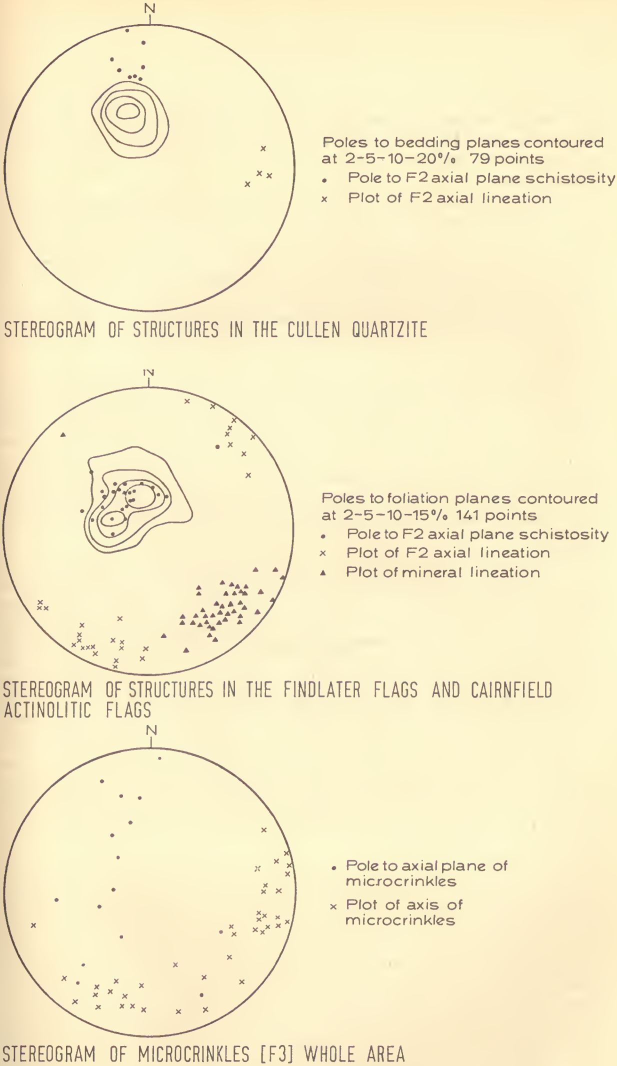


FIG. 5. *Stereograms showing the orientation of structures in the Dalradian. All the diagrams are geographically orientated and based on the lower hemisphere projection of a Schmidt net*

large antiforms. The folds are tight to almost isoclinal, the angle between the limbs being commonly within the range of 10 to 15 degrees (Fig. 4). When measured parallel to the axial plane the thickness of individual beds remains approximately constant in all parts of the fold. The folding is therefore of 'similar' type.

An axial plane schistosity is well developed nearly everywhere. Although minor folds are rare in the Cullen Quartzite a schistosity which is probably equivalent to the axial plane schistosity in the Cairnfield and Findlater Flags is found in the more micaceous beds. It dips in the same direction as the bedding but at a steeper angle. The angle between the bedding and the schistosity varies according to the lithology. In slightly micaceous quartzite it is usually over 50 degrees. On passing into more micaceous quartzite it decreases to between 20 and 40 degrees while in mica-schist the bedding and schistosity are sub-parallel.

In the Burn of Tynet area the segregation of actinolite and biotite into layers parallel to the schistosity has locally led to the formation of a new lithological banding. In a typical slice (47058) showing the new banding there is a fairly regular alternation of thin (about 0·1 mm) bands composed largely of actinolite with thicker (about 1·0 mm) bands composed of biotite, calcite and quartz. The bedding follows a wavy course across the section almost at right angles to the new banding. In places the bedding is disrupted by slip surfaces which are parallel to the new banding (48295). Very locally it is almost entirely obliterated (47056).

Although the F2 minor folds are usually accompanied by a penetrative schistosity, relics of an earlier (F1) schistosity have been detected at two localities. In the Core Burn 280 yd downstream from Newton of Letterfourie [437610] a schistosity which is parallel to the overturned limb of a large fold is distorted by very closely spaced puckers. The axial planes of the puckers are parallel to the axial plane of the large fold. In the quarry on Braes Cairn [396584] muscovite flakes lying parallel to the bedding have a chevron arrangement due to the presence of a very intense microcrinkling (47060). Some of the muscovites and most of the biotites are orientated parallel to the axial planes of the puckers and it is clear that the early (F1) fabric is partly overprinted by a newer (F2) fabric.

Lineations are often associated with the minor folds (Figs. 5 and 6). An axial lineation due to the intersection of bedding and schistosity forms a striping on the schistosity surfaces of the Findlater and Cairnfield Flags. In the Cullen Quartzite it is possible at some localities to measure an intersection lineation plunging towards the east.

In the Findlater and Cairnfield Flags a mineral lineation with a consistent orientation plunges towards the south-east at an average of 25 degrees. It appears as a fine striation on the axial plane schistosity and the angle it makes with the axial lineation is usually in the region of 65 degrees. A section (47065A) from the Cairnfield Flags cut parallel to the schistosity shows that the striation is a penetrative lineation due mainly to the biotite fabric and partly to a preferred orientation of the c-axes of actinolite. The quartz is equigranular and plays no part in the formation of the lineation. Most of the biotite flakes lie parallel to the schistosity. However, a significant proportion have their basal planes lying at an angle to the schistosity but parallel to the mineral lineation (Fig. 7). There is an intimate fabric relationship between the F2 axial plane schistosity and the

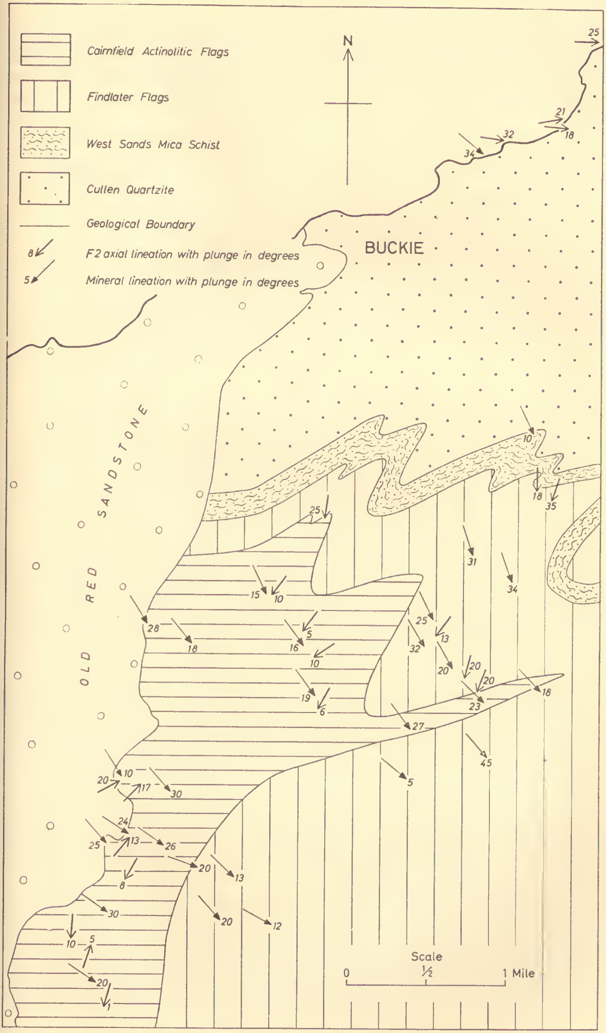


FIG. 6. *Sketch map showing lineations in the Dalradian*

mineral lineation and no evidence that one is superimposed upon the other. In view of this, and the fact that with only one doubtful exception folds with axes parallel to the mineral lineation have not been found, it is tentatively concluded that the mineral lineation is a structure parallel to the *a* or *A* axis of the F2 folds.

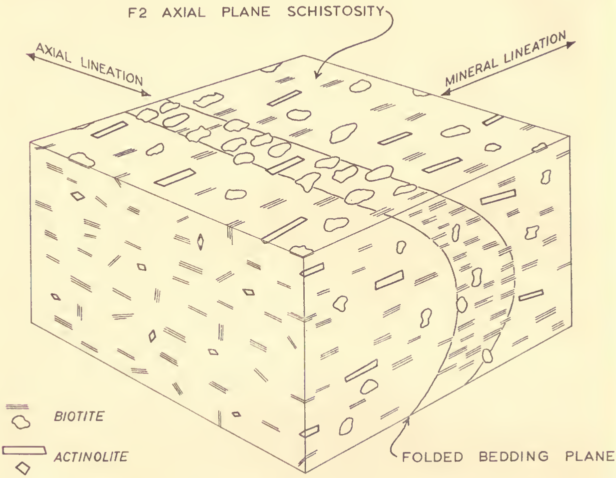


FIG. 7. *Block diagram showing the fabric of the Cairnfield Actinolitic Flags in the Burn of Tynet area*

Microcrinkling (F3) of the F2 axial plane schistosity is commonly found in the Cairnfield and Findlater Flags and in mica-schist horizons in the Cullen Quartzite. The orientation of the axes and axial planes of the microcrinkles is variable (Fig. 5) and two sets sometimes occur within one exposure. It is probable that there is more then one generation of microcrinkling but owing to the lack of exposures it has not been possible to confirm this. In slice (47067–8, 48133) the microcrinkles are asymmetrical and a notable feature is the concentration of mica in one limb of each crinkle. This is presumably the result of solution and migration of quartz during deformation. In the micaceous limb the angle between the schistosity and the axial plane of the crinkle may be very small and this gives rise to a strain-slip cleavage.

The latest fold structures (F4) consist of small monoclines of brittle style. These are uncommon but have been recorded from a few localities in the Cairnfield and Findlater Flags. The axial planes strike east-north-east and the dip is either towards the south-south-east at approximately 45 degrees or towards the north-north-west at a similar angle. Folds with north-north-west-dipping axial planes are the more common. Conjugate pairs of monoclines are rarely seen but poor examples occur in Tarrymount Quarry. The axial planes are frequently broken and they sometimes merge into reversed faults.

A table showing the sequence of minor structures in the Dalradian is given below.

F1 Schistosity parallel to bedding

F2 Tight minor folds. Axial plane schistosity. Axial intersection lineation. Oblique mineral lineation

F3 Microcrinkling (possibly two or more episodes)

F4 Brittle-style monoclinal folds

F1, F2, etc. merely describe the local succession of minor structures in so far as they can be determined and no correlation with sequences described from other parts of the Highlands is implied.

MAJOR STRUCTURES

The metasediments exposed between Cullen and Sandend on the Banffshire coast (Banff Sheet 96) form an unbroken succession younging towards the south-east. Inland the same general succession is maintained although a complication is introduced by the presence of the Cairnfield Actinolitic Flags. On the coast the beds are vertical or steeply inclined towards the south-east. Inland the dip becomes mucb less steep (Fig. 8).

In the Drybridge area the outcrop of the West Sands Mica-Schist is shifted in stages towards the north. Evidence of this is found in the Burn of Letterfourie where the Findlater Flags are directly along the strike from tbe Cullen Quartzite in the Hill of Maud area (Banff Sheet 96). Similar evidence is found between Clean Hill and the Burn of Cairnfield. The northward shift of the outcrops could be due to north-west trending faults but supporting evidence for faults of this magnitude is lacking. A more likely explanation is that it is due to the presence of large F2 folds (Fig. 8). There are numerous tight minor folds plunging towards the south-west and overturned towards the north-west and large-scale folds of the same type and orientation are probably responsible for the shift of outcrops. This interpretation is supported by axial plane-bedding relationships in the Core Burn and the Burn of Cairnfield. In most places the axial planes of minor folds dip more steeply than the bedding but locally the reverse relationship is found, showing that large folds cross the streams. The increase in tbe width of the outcrop of the Findlater Flags from less than a mile to more than four miles as it is traced inland from the coast is partly due to a decrease in the angle of dip, but the main cause is probably an increase in the amount of large- and intermediate-scale F2 folding (Fig. 8).

In an earlier section it was suggested on litbological grounds that the Cairnfield Flags are probably equivalent to tbe Crathie Point and Garron Point groups of tbe Banffshire coast section. If this correlation is correct then it follows that the present position of the Cairnfield Actinolitic Flags must be due to a major tectonic structure. A possible interpretation is tbat tbe Cairnfield Actinolitic Flags occupy tbe core of a synform (Fig. 9). The supposed synform could be a major structure related to the minor F2 folds and to the large F2 folds in the Drybridge area.

The major fold in the West Sands Mica-Schist at Lintmill (Banff Sheet 96) has a different orientation from the folds at Drybridge. It will be seen from the block diagram (Fig. 8) that the axial plane strikes north-north-west while the axis plunges very steeply towards the east. The axial planes of minor F2 folds follow the general trend of the bedding round the fold showing that the Lintmill structure is post-F2 and therefore later than the large folds at Drybridge.

The swing in strike of the quartzite west of the Hill of Stonyslacks is due to a very open synform plunging to the south-east. This structure probably developed at a late stage in the tectonic history of the area.

METAMORPHISM

All the Dalradian rocks of the Buckie district have undergone extensive recrystallization and the growth of new minerals. Even the Cullen Quartzite, which contains the least altered rocks, is completely recrystallized and contains secondary biotite and locally a little garnet. In spite of this, original sedimentary structures are well preserved and occasionally it is possible to recognize the sites of clastic grains. The pelitic (garnet-biotite-schist) bands in the Cullen Quartzite show that this part of the Dalradian reached the garnet grade of metamorphism. The semipelitic rocks of the Findlater and Cairnfield Flags are fine-grained with well-preserved sedimentary laminations and superficially they appear to have suffered only a low to moderate degree of metamorphism. However, the occurrence of kyanite and staurolite shows that locally at least a high grade of metamorphism was reached.

The relationships between the various minerals and the minor structures indicate that metamorphism took place in several stages. The earliest metamorphism probably took place prior to the F2 folding. Evidence of this is found in the garnets of the West Sands Mica-Schist. These garnets are either rounded or angular with signs of fracturing and a schistosity, believed to be related to F2 folds, is wrapped round them. Straight or slightly curved inclusion trails lying at a variable angle to the schistosity show that the garnets were rotated during F2 folding. The inclusions, which are much finer in grain than the groundmass, show that there has been a considerable increase in grain-size subsequent to the crystallization of the garnets. Evidence of pre-F2 metamorphism is occasionally found in the Findlater and Cairnfield Flags. Specimens collected from a locality in the Core Burn and a quarry near Braes Cairn contain relics of a pre-F2 schistosity. This schistosity is defined by an alignment of biotite and muscovite and it is concluded that these micas crystallized during the period of F1 folding.

From the foregoing evidence it is likely that the Dalradian rocks of this area were already in the garnet grade of metamorphism at the beginning of the F2 period of folding. The widespread development of the F2 axial plane schistosity shows that biotite and muscovite were crystallizing during the F2 folding. The absence of marginal alteration of the pre-F2 garnets in the West Sands Mica-Schist suggests that garnet was stable. In the Burn of Tynet area needles of actinolite tend to lie parallel to the F2 axial-plane schistosity and to a lineation which is probably related to the F2 folds. Thus, it appears that, locally at least,

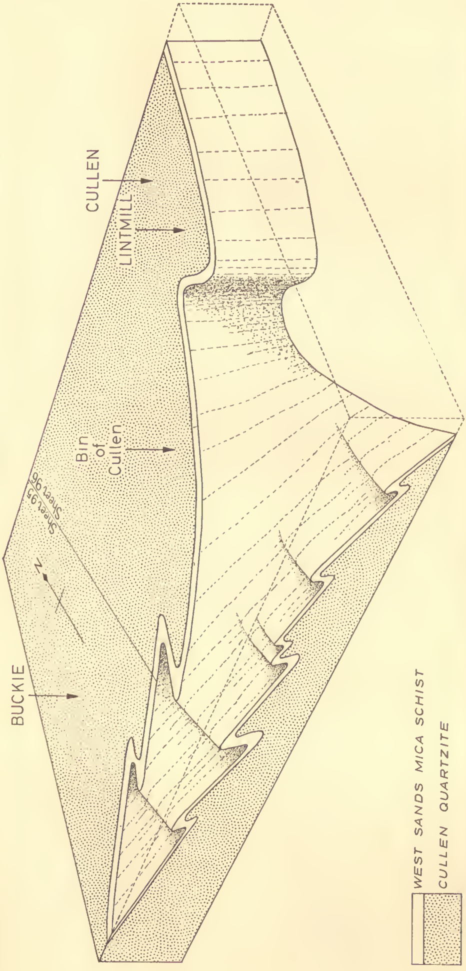


FIG. 8. *Block diagram showing fold structures in the Dalradian between Buckie and Cullen. Note increase in angle of dip from WSW. to ENE. and also the dying out of folds in the same direction*

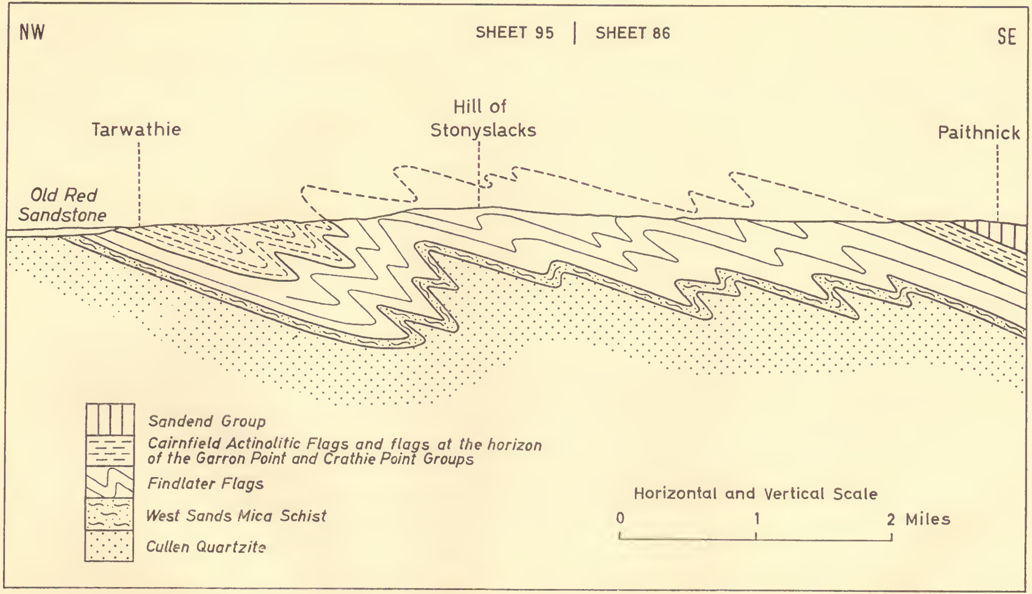


FIG. 9. *Section across the Dalradian from Tarwathie to Paithnick. The correlation of the Cairnfield Actinolitic Flags with the combined Crathie Point and Garron Point groups is conjectural*

actinolite was crystallizing during the F2 folding. Farther north in the Burn of Cairnfield area the actinolite belongs to a later period of metamorphism which is described below.

In the Cairnfield Flags porphyroblasts of actinolite, kyanite and staurolite cut across the F2 axial-plane schistosity. They have a random orientation and evidently grew during a period of static metamorphism which followed the F2 folding. The post-F2 actinolite occurs as stout prisms containing inclusions of quartz which have the same grain-size as the groundmass. In places, inclusion trails show that micro-folds, probably of F2 age, have been overgrown by actinolite. Porphyroblasts of kyanite and staurolite contain trails of elongated ore grains showing that the F2 schistosity passes undisturbed through the porphyroblasts and it is clear that these minerals are post-tectonic with respect to the F2 folding. Biotite only rarely forms porphyroblasts but in the staurolite-biotite-schist of the Burn of Auchiefow large randomly orientated biotites cut across the schistosity. They enclose small inclusions of muscovite which by their orientation show that the schistosity passes undisturbed through the porphyroblasts. The growth of porphyroblasts was probably accompanied by the recrystallization of the granular components, quartz, calcite, feldspar and epidote although textural evidence of this is lacking.

Later metamorphism has been relatively slight so that the minerals seen in the rocks at the present time very largely represent assemblages that were in equilibrium during the period of static metamorphism which followed the F2 folding. The following table gives the mineral assemblages found in the various Dalradian horizons. Minerals such as chlorite and some white mica which are known to have formed during late retrograde metamorphism are omitted; those in brackets are absent at some localities.

CULLEN QUARTZITE
Quartzite assemblage
Quartz-potash feldspar-muscovite-(biotite-garnet)
Calc-silicate assemblage
Quartz-calcite-clinozoisite-garnet-biotite-(plagioclase)
Pelitic assemblage
Quartz-biotite-muscovite-garnet

WEST SANDS MICA-SCHIST
Muscovite-biotite-quartz-garnet

FINDLATER FLAGS
Biotite-muscovite-quartz-acid plagioclase-(garnet)

CAIRNFIELD ACTINOLITIC FLAGS
Calcareous assemblages
Actinolite-biotite-quartz
Actinolite-biotite-calcite-quartz
Actinolite-biotite-epidote-quartz-(calcite-scapolite-plagioclase)
Biotite-epidote-muscovite-quartz
Biotite-epidote-muscovite-quartz-calcite
Biotite-calcite-quartz
Aluminous assemblages
Biotite-muscovite-staurolite-quartz
Biotite-muscovite-staurolite-kyanite-quartz-plagioclase
Biotite-kyanite-quartz

The association of calcite with an amphibole in the tremolite-actinolite series, and calcite with epidote, together with the absence of diopside, grossularite and idocrase, suggest that the calcareous rocks of the Cairnfield Actinolitic Flags are in the greenschist facies of metamorphism (Fyfe, Turner and Verhoogen, 1958, p. 224). However, the presence of staurolite and kyanite indicates that the pelitic rocks are in the almandine amphibolite facies. No explanation of this juxtaposition of assemblages characteristic of different metamorphic facies has been attempted.

Certain minor metamorphic changes which took place after the period of post-F2 static metamorphism remain to be described. Some of the kyanite porphyroblasts in the Cairnfield Actinolitic Flags are slightly bent and marginally altered to white mica. This post-crystalline deformation and alteration may be related to the period or periods of late tectonic microcrinkling. Staurolite in a pelitic schist from the Burn of Auchiefow shows considerable alteration to chlorite. Microcrinkling is well developed and the alteration is probably related to the formation of this structure. The ability of quartz to recrystallize during the development of microcrinkles is demonstrated by the segregation of quartz and mica into opposite limbs of each crinkle (p. 24).

The minor metamorphic changes which are probably associated with the F3 microcrinkles marked the end of a sequence of mineral changes which converted the original Dalradian sediments into their present condition. Temperature and pressure values were evidently so low during the F4 folding that no significant mineral changes took place during this final period of movement.

The following table gives a summary of the main metamorphic events and attempts to show how they are related to stages in the tectonic history of the area.

Pre-F2 metamorphism	Growth of garnet, biotite and muscovite
F2 syntectonic metamorphism	Growth of biotite, muscovite and acicular actinolite. Garnet stable
Post-F2 static metamorphism	Growth of porphyroblasts of actinolite, kyanite, staurolite and biotite. Garnet stable
F3 syntectonic metamorphism	Alteration of kyanite to white mica and staurolite to chlorite. Recrystallization of quartz
F4	No mineral changes

This sequence appears to agree fairly well with that established by Johnson (1962) in the Dalradian of the Banffshire coast section. In particular the post-F2 period of static metamorphism is almost certainly equivalent to the post-F2 period of static metamorphism in Johnson's sequence.

Quartz Veins

Veinlets of quartz are abundant in the Cullen Quartzite and are particularly well seen in the shore section at Buckie. The veinlets fill a single set of joints dipping to the west-north-west at between 50 and 60 degrees. They are usually less than ½-inch thick but locally they may reach as much as 1½ inches. In addition to quartz there are, in the veins, small amounts of feldspar, tourmaline, muscovite, chlorite, pyrite and possibly rutile and siderite. A thin section (47077) of a vein from a small disused quarry on Clean Hill [435637] shows abundant euhedral tourmaline occurring as inclusions in a mosaic of interlocking quartz grains. The tourmaline crystals are colour-zoned, the cores being green while the outer parts are yellowish-brown. Wall-rock alteration in the form of a yellowish discoloration of the quartzite is usually present. The altered zone is up to 3 in wide.

The quartz veins do not extend up into the Old Red Sandstone. They are cut by baryte veins (p. 126). F.M.

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Chapter IV

MIDDLE OLD RED SANDSTONE

Introduction

The Dalradian rocks in the east of the Elgin (95) Sheet-area are unconformably overlain by breccias and conglomerates which pass upwards into sandstones and rare nodular limestones which bave yielded fish remains of Middle Old Red Sandstone age. These strata can be followed by intermittent exposures south-westwards along the high ground soutb of the Elgin (95) Sheet to the north of the Glen of Rothes. West of the line of the Rothes Fault a small triangle of Middle Old Red Sandstone enters the extreme south of the sheet just east of the River Lossie. Near Scaat Craig at tbe entrance to the Glen of Rothes the Middle Old Red Sandstone is overlain by Upper Old Red Sandstone (Hinxman and Grant Wilson 1902, p. 63) though the contact is not exposed. On the Elgin (95) Sheet tbe upper boundary of the Middle Old Red Sandstone is fixed within about 300–400 yd farther east at Fochabers Bridge where the arenaceous strata overlying the Dipple Fish Bed are succeeded at Redhall Quarry by beds carrying *Bothriolepis* (Taylor 1900, p. 47), though once again the actual contact is apparently not exposed. On the basis of 'average dip' readings the Middle division of the Old Red Sandstone appears to be between 1000 and 2000 ft thick, though these figures may well be in error because of the possible existence of concealed faults. If, as seems possible, the Old Red Sandstone strata on the south side of the Moray Firth are on the southern edge of a basin of deposition, thickening of the deposits in a north-westerly direction might occur.

West of Buckie a number of exposures show Middle Old Red conglomerate unconformably overlying a few feet of limestone, red sandstone and shale, which in turn rest unconformably on the Dalradian Cullen Quartzite. It is not clear whether these unfossiliferous beds, here called tbe Buckie Beds, are also of Middle Old Red Sandstone age or whether they are older (p. 42). Unfossiliferous beds below unconformable Middle Old Red Sandstone conglomerate are known at several localities in north-east Scotland, and are regarded as being of Lower Old Red Sandstone age by Westoll (1964, p. 446). The evidence for the age of the Buckie Beds is discussed further below.

Lithology

Though the Middle Old Red Sandstone is on the whole better exposed than the Upper division, correlation of the various horizons is precluded because of faulting and to some extent by the scarcity of fossils. However, there are a number of fairly continuous sections which in two cases total 400 ft in thickness, sufficient to give a good indication of the lithology. Thus in the Dipple section (p. 34) a little over a quarter of tbe beds are conglomeratic and most of the remainder red sandstone. In the Tynet Burn section the proportion of conglomerate and breccia is about 50 per cent, and on the coast west of Buckie the coarser grained rocks are in the majority.

TABLE I

PERCENTAGE COMPOSITION OF MIDDLE OLD RED SANDSTONE CONGLOMERATE PEBBLES

	Locality								
	1	2	3	4	5	6	7	8	9
Quartzite (mainly Cullen Quartzite)	87	65	68	82	76	78	62	70	77
Feldspathic flags and psammitic granulite ..	7	32	24	13	18	16	32	20	14
Micaceous flags and mica schist	—	—	6	1	—	1	5	—	4
Vein quartz	1	2	2	3	2	1	1	2	2
Granite	1	1	—	1	2	1	—	4	—
Microgranite	—	—	—	—	—	1	—	2	3
Feldspar-porphyry ..	—	—	—	—	—	1	—	—	—
Andesite	—	—	—	—	—	1	—	1	—
Quartz-porphyry ..	1	—	—	—	—	—	—	1	—
Limestone	—	—	—	—	2	—	—	—	—
Sandstone	3	—	—	—	—	—	—	—	—
No. of pebbles counted	91	106	102	140	146	140	140	92	85

1. Buckie shore [410653]
2. Boghead [356593]
3. Botanybay Burn [372594]
4. Dipple Brae [334591]
5. Tynet Burn, above Lower Fish Bed [383619]
6. Gollachy Burn, overlying andesite [406646]
7. Burn of Buckie [420652]
8. Bellie Brae [354606]
9. Birnie Bridge [202585]

A study of the pebbles and boulders in the conglomerates (Table I) shows that at nine localities scattered across the map there is considerable uniformity of pebble content, well over 90 per cent being derived from the Cullen Quartzite and associated rocks, thougb at Birnie Bridge much of the quartzite may be Moinian. A small proportion of the psammitic pebbles may be of Moine granulites. The sandy matrix of the conglomerates and also some of the larger pebbles, particularly the granitic rocks, are commonly decayed, and in the beds on Whiteash Hill and at the edge of the high ground south-west of Fochabers some of the pebbles are decomposed to a sandy clay. It seems likely that such decomposition is related in part to the deep weathering noted elsewhere in north-east Scotland (Fitzpatrick 1963).

The sandstones in the Middle Old Red Sandstone are usually brick-red in colour and calcareous (Mackie 1897, p. 171; 1901, p. 58) as are the thin interbedded horizons of shale and siltstone. Concretionary bands and nodules of limestone are present in some of the shaly rocks, and at the fish bed localities preserve the complete fossil skeletons of fish.

Details

Birnie District. The bank of the River Lossie flanking Hillhead Wood, just beyond the southern boundary of Sheet 95, is composed almost entirely of liver-red conglomerate containing numerous sub-angular fragments over a foot in diameter, mainly of quartzite and Moine psammitic granulite, in a poorly-sorted sandy matrix. Although the cliffs range up to 100 ft in height it is only occasionally possible to discern signs of stratification. Traces of bedding dipping between 40 and 70 degrees in directions between north and west can be seen, suggesting a scree or alluvial-cone origin. In places the conglomerate is decomposed.

A little farther north, at Birnie Bridge [202584], there are further outcrops of the coarse conglomerate, and downstream from the bridge for the next 200 yd, more variegated strata appear including coarse red and yellowish green pebbly sandstone, fine-grained conglomerate, and red and green shales. A three-foot bed of highly micaceous purple shale is rich in lenticles and nodules of fine-grained limestone. Some of the shale and sandstone horizons are patterned in pale yellowish-green markings that resemble worm tracks. In places it can be seen that such markings are related to joints along which reduction of the ferric oxides which colour the rocks has occurred. The dip is about 20 degrees to the north-west, and there are two sets of joints striking N. 25° E. and N. 70° E. respectively.

West bank of the Spey. Solid rock is exposed in a terrace scar of the River Spey from a locality [330589] 600 yd north of Dipple to Fochabers Bridge [340594] giving the largest single undisturbed section of Middle Old Red Sandstone on the sheet, totalling some 400 ft of strata in all. These rocks, which dip on the average about 6 degrees towards the north or north-west, comprise the following succession:

		Ft
9.	Cross-bedded red sandstone	30
8.	Interbedded red sandstone and conglomerate	110
7.	Cross-bedded red sandstone	30
6.	Boulder conglomerate	60
5.	Cross-bedded red sandstone	55
4.	Nodule Bed (Sweethome Nodule Bed)	4
3.	Cross-bedded red sandstone	90
2.	Nodule Bed (Dipple Fish Bed)	5½
1.	Sandy limestone passing down into calcareous sandstone	1½

At Dipple Brae [330588] the Dipple Fish Bed (2) was at one time quarried and on clearing the talus the following section was exposed:

	Ft	in
Terrace gravel	–	–
Flaggy red sandstone with shaly partings	3	0
Dark brown micaceous sandstone	–	6
Red silty sandstone	1	0
Red sandstone	2	2

	Ft	in
Dipple Fish Bed:		
Sbale, fissile, red, with purple bands. Occasional fish scales, doubtful plant remains. Nodules and concretions lens-shaped or composite, $\frac{1}{4}$ in to 12 in across, up to 3 in thick. Light greenish cores, reddish margins. Concretions contain remains of fish	5	4
Red and green mottled limestone with fish remains	–	$2\frac{1}{2}$
Reddish-brown sandy limestone with shaly partings. Beds $\frac{1}{2}$ in to $1\frac{1}{2}$ in. Probably passes down into flaggy calcareous sandstone	1	$5\frac{1}{2}$

During the revision survey the following fish fauna was recovered: *Dickosteus thrieplandi* Miles and Westoll, *Osteolepis sp.*

At Sweethome [332590] a section about 20 ft high shows the upper part of the sandstone (Bed 3) of the above succession together with the overlying nodular bed (4). The sandstone is flaggy, and mainly red in colour but with a few greenish spots, and, at intervals, thin horizons of soft, red, micaceous siltstone and scattered small pebbles. Small-scale cross-bedding is common (units 1 to 9 inches in thickness). Immediately north-east of the house a 4-ft bed of shale with calcareous nodules up to 3 in across comes in near the top of the section. The upper part of the shale is purple and contains more nodules than the lower half, which is red. A bed of coarse-grained, greenish, micaceous sandstone with a gritty and in places pebbly base overlies the nodular shale. The nodules at this locality have not as yet yielded any fossils.

About 100 yd north-eastwards along the cliff the red sandstone (5) is overlain by the coarse red boulder conglomerate (6). An intercalated bed of red sandstone occurs at an old quarry [334591].

Bed 7 is well seen in the old quarry [335592], 470 yd NE. of Sweethome. Here a section shows about 25 ft of flaggy cross-bedded red sandstone with a number of bands of fine-grained conglomerate. Beds of silty micaceous red sandstone are common. The section is overlain by till at the base of which are several feet of churned-up sandstone.

Between this quarry and Fochabers Bridge there is a continuous cliff-section exposing up to 30 ft of rock at any one point. Passing north-eastwards from the quarry, beds of conglomerate (item 8 in the above succession) become more frequent, soon making up about a third of the strata, individual beds reaching about 6 ft in thickness. Bands of nodular sandstone and siltstone are common. The uppermost band of conglomerate of this group disappears below water-level about 30 yd south of the bridge and is followed by some 30 ft of rather soft cross-bedded red sandstone which contains small ferruginous concretions. These concretions occur only at the top of the cliff and may therefore be of recent origin.

At a locality [33825939] about 200 yd SW. of Fochabers Bridge, the sole of a bed of conglomerate at the contact with laminated sandstone below shows a number of parallel grooves trending E. 30° S. The grooves are some 1 to 3 in deep and 6 to 12 in apart. Similar well-preserved structures $1\frac{1}{2}$ in to 2 in deep and 1 to 2 ft apart, parallel or slightly curved, and tending N. 5° E. are visible at the base of a conglomerate bed 100 yd SW. of the Bridge.

East bank of the Spey. There are a number of exposures of unfossiliferous strata, presumably of Middle Old Red Sandstone age, in the main river terrace cliff between Fochabers and Upper Dallachy. East of Boghead [354591] there are several exposures of soft red conglomerate in the vicinity of the mill dam, and at a gravel pit 300 yd ENE. of Boghead, 17 ft of soft bouldery conglomerate with sandstone lenticles is exposed. The dip is nearly horizontal. Farther north, rock is near or at the surface at the foot of the cliff and there are scattered outcrops of red conglomerate and sandstone. Some 200 yd S. of Upper Dallachy at an exposure [361623] shale pellets occur in cross-bedded red sandstone.

Fochabers to Bridge of Tynet. In the wooded area of Whiteash Hill several burns have eroded deeply into the till and solid rock. Most of the exposures are of red conglomerate which is generally soft and friable and in parts considerably weathered, with horizons of ferruginous pan. Exposures in Red Slack [367583], Nashag Burn [370586] and Botanybay Burn [372594] show up to 30 ft of red conglomerate with partings and thin bands of sandstone with an almost horizontal dip.

A little to the east the unconformity of Middle Old Red Sandstone on Dalradian schist is seen in the headwaters of the Aulrothie Burn [390580]. Here, in a small side-stream about 100 yd above its junction with the Aulrothie Burn, soft, cross-bedded, red sandstone dipping north-west at 5 degrees rests on semi-pelitic flags. Some 300 yd farther south similar red sandstone contains numerous thin bands of breccia made up largely of fragments up to 6 in across of the underlying schist.

The beds at a greater distance from the unconformity are well exposed in Kiln Stripe [387585], which is a gully eroded to a depth of 40 ft, mainly in Old Red Sandstone. The main rock type is a soft brick-red sandstone with subordinate breccias and sparse bands of boulder conglomerate. Individual beds are lenticular, and rarely reach more than 10 ft in thickness.

From Kiln Stripe to Chapelford [389600] the Aulrothie Burn has excavated banks up to 40 ft high in conglomerate and breccia which give way to sandstone at the north end of the section. The conglomerates are reddish and made up of angular to sub-rounded pebbles up to 2 in across in an unconsolidated matrix. Thin lenticular bands of cross-bedded sandstone are abundant and distributed fairly regularly throughout the conglomerate.

In the upper Tynet Burn there is a good exposure of the highly irregular unconformable base of the Middle Old Red Sandstone in one of the tributaries, the Ardmachie Burn [402594], 400 yd SSW. of Mains of Oxhill. The flags below the unconformity are thinly banded, very soft and much reddened, the reddening persisting upstream for upwards of 20 yd from where the unconformity crosses the stream. The unstratified basal breccia is composed of angular slabs of the underlying flags ranging from less than 1 in to 1 ft in length, set in a bright red sandy matrix.

Lower Tynet Burn. Between Bridge of Tynet [384614] and Lower Mills of Tynet [383618], the stream becomes deeply incised in boulder clay, and coarse conglomerate and red sandstone crop out in a meander scar some 200 yd below the bridge.

Below Lower Mills of Tynet is the well-known Tynet fish locality (Fig. 10). The measured section is as follows:

		Ft
8.	Red sandstone with a few lines of pebbles	12
7.	Purple shale with limestone nodules (UPPER NODULE BED)	about 22
6.	Red sandstone and shale with calcareous concretions	about 23
5.	Conglomerate with lenticles of red sandstone	10
4.	Red shale passing down into red sandstone	7
3.	Conglomerate with thin bands and lenticles of red sandstone	13
2.	Red and green shale with limestone nodules (LOWER NODULE BED)	8
1.	Conglomerate with numerous angular pebbles	3
	Total thickness of measured section	98

The Lower Nodule Bed (2) is a red and green shale with ribs and nodules of hard pink and cream limestone and thin ribs of calcareous sandstone. A thin band of soft pebbly sandstone occurs near the base. Mr. P. Brand collected unidentifiable fish-scales from the nodules.

Bed 6 is an interbanded red shale and sandstone with nodules and thin bands of lustre-mottled calcareous sandstone. Greenish streaks occur in some of the shales.

At the best exposures of the Upper Nodule Bed (7), on the left bank of the stream adjacent to the fault shown on Fig. 10, about 15 ft of purple silty clay with bands and nodules of hard limestone is seen. The limestone is cream in colour with patches of red. According to Malcolmson (1859, plate xi, fig. 9), three horizons of 'shale with ichthyolites' occurred here, and Wallace (1880, p. 333) mentions two fish-bearing horizons within the nodule bed. Wallace records *Osteolepis* and *Pterichthis* from the lower horizon and *Diplopteris*, *Cheirolepis* and *Cheiracanthus* at the upper, some 4½ ft above the lower. A list of fauna is given in Appendix II, p. 135.

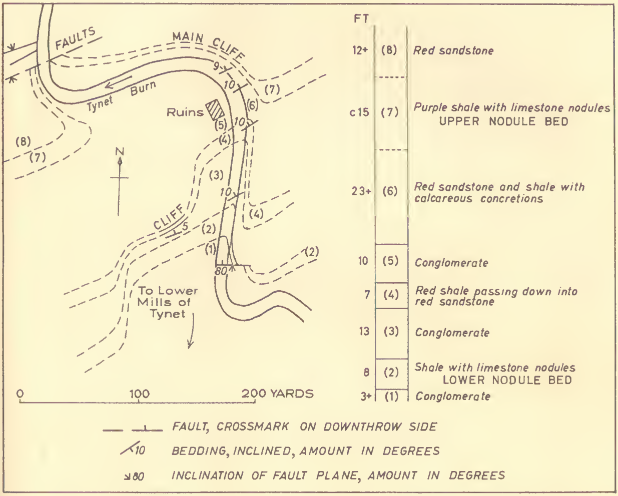

FIG. 10. *Sketch map of outcrop of fish-bearing beds, Lower Mills of Tynet*

A few fossils have been found at other levels. Malcolmson mentions for instance that *Dipterus* was got (probably from Bed 6), and Wallace records *Coccosteus* from a lower horizon (probably Bed 4).

Bed 8 is cut off by a zone of faulting (Fig. 10) from the 400 ft or so of gently-dipping beds exposed farther downstream.[1] At the base of these is a red boulder conglomerate with thin sandstone lenses, some 130 ft thick. These strata grade upwards through interbedded red sandstone and conglomerate to cross-bedded sandstone with only occasional thin bands of conglomerate. At a locality [382623] 300 yd upstream from Lower Auchenreath and some 240 ft above the lowest bed of the conglomerate is a 6-ft band of red shale with ribs of limestone overlain by a considerable thickness of sandstone with subordinate bands of conglomerate and red siltstone. A band of purple marly shale with calcareous nodules (the Tannochy nodule bed), formerly seen 300 yd upstream of the junction of the Core Burn with the Tynet Burn, is reputed to be

[1] The sections are discontinuous and the thicknesses given assume that faults are small or absent.

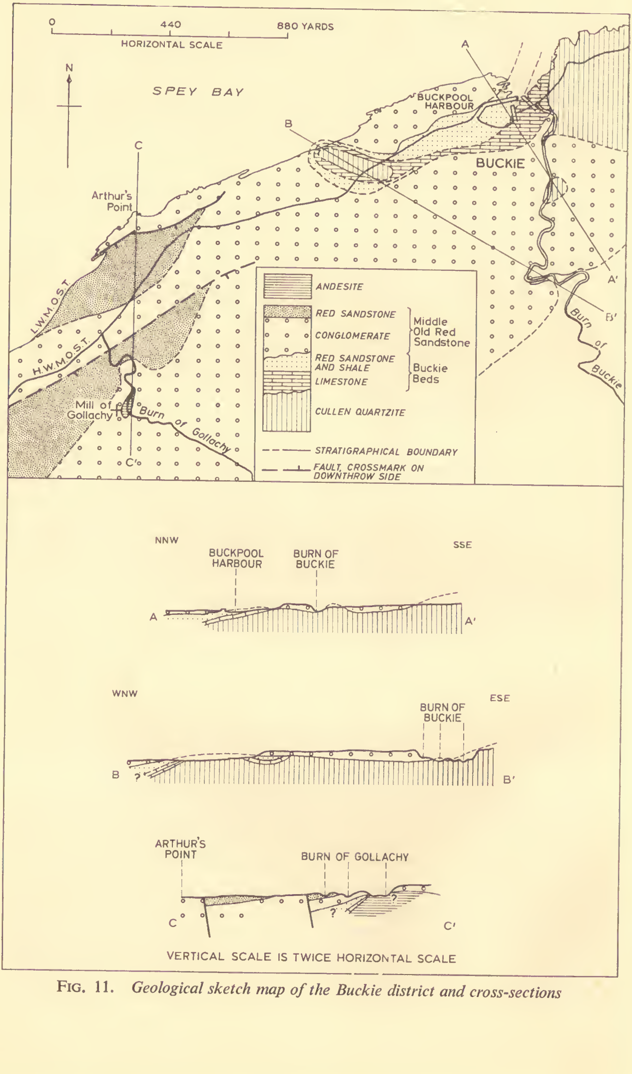

FIG. 11. *Geological sketch map of the Buckie district and cross-sections*

duplicated by a small fault. It has not yet yielded fossils. The remaining sections in the lower Burn of Tynet are of soft thinly bedded red sandstone with streaks of white clay.

Portgordon to Buckie. The detailed field relations of the strata in the Portgordon–Buckie district are shown in Fig. 11. On the shore west of the harbour at Portgordon flaggy cross-bedded red sandstone with subordinate pebbly bands and one or two thin (1 ft) beds of red shale are disposed in a very shallow, northerly-plunging anticline. At the west end of the section at Porttannachy there are two small strike faults with the downthrow to the south-east.

East of Portgordon the Old Red Sandstone is well-exposed between tidemarks as far as the mouth of the Burn of Buckie. At the west end it consists of boulder conglomerate apparently overlain by red sandstone with very subsidiary thin seams of red shale, some of which show desiccation cracks. Part of the conglomerate is calcareous and at one or two points it carries veinlets of barytes. The dip is very gentle, mainly towards the north-west, and the beds are traversed by a number of small strike faults.

Midway between Arthur's Point [406652] and the harbour at Buckpool an inlier of Cullen Quartzite extending seawards is surrounded by a succession of calcareous beds (the Buckie Beds) underlying the unconformable base of the conglomerate (Plate IIIA). Thin veinlets of barytes occur in both the quartzite and the overlying beds. The succession is as follows:

		Ft
7.	Conglomerate	
	unconformity	
6.	Interbedded red flaggy sandstone and red shale with ribs of calcareous sandstone	7–12
5.	Limestone, bedded, with thin bands of red shale towards top	3
4.	Limestone with abundant fragments of quartzite	2
3.	Limestone, massive, with scattered fragments of quartzite and disseminated crystals of barytes	7
2.	Limestone, pink, with concretionary structure and angular fragments of quartzite	4½
1.	Thin stratum of banded concretionary limestone, the bands running parallel to the surface of the quartzite	—
	Total	28½
	unconformity	
	Cullen Quartzite	

On the west side of the inlier a small fault with carbonate-impregnated breccia is seen adjacent to the quartzite, but at other points the limestone rests directly on the quartzite. On the east side both unconformities are well seen, and the conglomerate oversteps 5 ft of Buckie Beds. The significance of the unconformity below the conglomerate is in doubt, since it could indicate either the junction of Middle with Lower Old Red Sandstone or merely represent a local non-sequence. No palaeontological evidence is as yet available.

The unconformity below the conglomerate can be traced eastwards along the coast near high tide mark, and just west of Buckpool Harbour about 10 ft of the underlying flaggy and calcareous beds are seen. On the east side of the harbour about 20 ft of coarse calcareous breccia and concretionary limestone rest on Cullen Quartzite.

In the Burn of Buckie, where it flows through the town, the uneven surface of Cullen Quartzite capped by up to 20 ft of bouldery red conglomerate and breccia can be seen at a number of points. Though the breccia is calcareous in places, the flaggy and limy Buckie Beds do not appear, having been completely overlapped. A fragment of fish was found by Malcolmson (1859, p. 347, plate xi, fig. 10) in sandstone at the top of a conglomerate section here though the exact location is doubtful.

Buckie to Portessie. Small outliers of the basal breccias and sandstone of the Middle Old Red Sandstone occur on the coast between Buckie and Portessie and are probably the remains of deposits which infilled an east-north-east-trending hollow between the present coastline and the offshore reefs of quartzite. At one locality [444667] the basal breccia with quartzite fragments up to 2 ft across, is overlain by beds of red boulder conglomerate and pebbly sandstone cut by veinlets of barytes. Similar, but smaller outliers occur in the raised beach cliff [44426660] and on the shore to the north-east [44756726].

Burn of Gollachy. About 200 yd W. of Auchentae there is a small exposure of breccia in the stream bed [410640], and breccia was formerly seen at a few points downstream for a distance of 250 yd. An intercalated shale band yielded scales of *Coccosteus* (Wallace 1880, pp. 335–6).

Lower down the burn, some 50 yd due NE. of Mains of Gollachy [406645], the Gollachy Burn andesite crops out by the ruins of the old Mill of Gollachy (Fig. 11). A few yards upstream from the ruins the stream plunges over a waterfall into a steep-sided ravine some 20 ft in depth. Porphyritic andesite is well exposed in the ravine and waterfall, and where fresh it is a dark grey rock, but where it is somewhat decomposed it is paler in colour. In many places it is characterized by strong platy jointing parallel to a planar orientation of the small white feldspar phenocrysts, the strike varying for the most part within a few degrees of north, and the dip being some 70 degrees towards the east.

The contact of the igneous rock with overlying strata is seen at several points. In the east wall of the ravine, between the mill ruin and the waterfall, conglomerate fills hollows eroded into the andesite. About 50 yd farther north, the top of the andesite has a brecciated appearance and fragments are included in an overlying pink limestone about 2 ft thick which is overlain in turn by 3 ft of red shale and sandstone dipping about 30 degrees to the north-west. These poorly-exposed strata are overlain by coarse conglomerate with thin lenticular sandstone bands, which overstep on to the igneous rock a few yards to the south. Pebbles of the andesite have been noted in the conglomerate near the Mill of Gollachy (Wallace 1880, p. 335), and also in the same conglomerate bed on the shore nearby.

Upstream from the waterfall reddish conglomerate is exposed in the right bank of the Gollachy Burn about 50 yd from the last exposure of andesite, the intervening rock being concealed by till and alluvium. The dip in the conglomerate is indistinct but probably low. A boulder of tbe andesite was seen in the conglomerate.

PETROGRAPHY

The lowest limestone of the Buckie Beds below the Middle Old Red Sandstone conglomerate on the Buckie shore (Bed 1, p. 39), is reddish and in thin section (48151), is seen to be dominantly fine-grained calcite interbanded with laminae and patches of coarse-grained calcite. The latter in part represent cavities now occupied by free-grown drusy calcite crystals. Also present are scattered rather corroded grains of quartz and feldspar and a few flakes of biotite and muscovite. The colour is given by disseminated yellow-brown and

PLATE III

A. BUCKIE BEDS. BRECCIA OF CULLEN QUARTZITE IN LIMESTONE BRECCIA
Shore 600 yd W. of Buckpool Harbour, Buckie (D 603)

B. CONCRETIONARY SANDSTONE WITH CALCAREOUS CEMENT ON SHORE NORTH OF GREENBRAE QUARRY, HOPEMAN
The uncemented sandstone between the concretions has been removed by wave action (D 687)

A

B

red-brown iron oxides, and there are isolated very sparse crystals of tourmaline and zircon. Bed 3 (48152) is similar except that the patches of coarse-grained calcite are haphazardly arranged and at two points there are small sheaves of barytes crystals (1 mm). The limestone overlying the Gollachy Burn andesite (48149), [406645] includes disoriented corroded fragments of the andesite together with quartz grains and a few flakes of biotite and muscovite.

A reddish micaceous siltstone, collected from Bed 6 (48153), [414654] consists of ahout 30 per cent of clastic material in a cement of calcite speckled with reddish brown and yellowish brown ferruginous matter. The clastic material with a grain-size of 0·1–0·2 mm is chiefly angular quartz, with much muscovite and biotite and a little feldspar.

Five thin sections of sandstone and siltstone from the Tynet Burn and Dipple areas were examined. In a grey sandstone streaked with red from just ahove the Dipple Fish Bed (p. 34) alternating coarse- and fine-grained bands (51191) are composed of corroded clastic quartz and microcline, with substantial amounts of muscovite and hiotite and a few grains derived from quartzite and from micaceous flags. The cement is largely calcite with pockets of kaolinite and a little opaque iron oxide. The heavy minerals include zircon, staurolite, epidote, rutile and sphene, all excepting sphene being minerals reported by Mackie (1925, pp. 153–5). In siltstones collected from the Sweethome Nodule Bed (51192, 51193) [33245903] and from near Focbabers Bridge (51194) [33895942], much of the cement is carhonate. Biotite and muscovite are common, and the same suite of heavy minerals is present. The reddish colour in these specimens is due to the presence of varying amounts of translucent red-hrown iron-oxide. A slice from a siltstone collected from the main Tynet Burn nodule bed (51196) [382620] sbows small patches of chlorite among the largely calcitic cement; garnet and rutile occur in the heavy mineral suite.

Stratigraphy

Two problems peculiar to the Middle Old Red Sandstone of the district involve (a) the stratigraphical position of the Buckie Beds below the conglomerate on the Buckie foreshore and the allied problem of the age of the Gollachy Burn andesite, and (b) the correlation of the fish-hearing strata.

(a) The exposures admit of two solutions: (i) The conglomerate in tbe Burn of Buckie south-east of Buckpool Harbour (Fig. 11) underlies the limestone and infills a deep trough between the nose of Cullen Quartzite west of tbe harbour and the main quartzite outcrop to tbe east and soutb-east. On this reading the conglomerate on the foreshore nortb of Buckpool Harhour is a higber hed than the conglomerate in the Burn of Buckie. (ii) Tbere is only one hed of conglomerate, and the Buckie Beds are entirely cut out and overstepped towards the south-east (Fig. 11, Section A–A′). This interpretation is preferred hecause it fits in with the known unconformahle relationship of the conglomerate to the Buckie Beds, and requires only shallow relief of the floor of Cullen Quartzite.

The Gollachy Burn andesite, exposed only at the one locality, has been interpreted hoth as a contemporaneous lava flow in tbe Middle Old Red Sandstone (Geikie 1878, p. 435; Sheet 95, 1st edition), and as a lava flow in tbe Lower Old Red Sandstone (Westoll *in* Watson and others 1948). According to the information obtained during this resurvey it is unconformably overlain by limestone and sandstone which are in turn cut out and overstepped by Middle Old Red Sandstone conglomerate (p. 40). In the section C–C′ (Fig. 11) it can be seen that the relationship is much the same as a little farther east, witb the andesite taking the place of the Cullen Quartzite. Thus if the preferred explanation of the Buckie exposures is accepted it is reasonable to suppose that the andesite is not only older than the Middle Old Red Sandstone conglomerate, but pre-dates the Buckie Beds. It is thus possible that the andesite is a minor intrusion in the Cullen Quartzite, exposed by accident of erosion in the same way as the quartzite nose between Arthur's Point and Buckpool Harbour. This interpretation explains the bigh angle of dip of the planar structure, and the resemblance of the Gollachy rock to the andesite sill intruding Cullen Quartzite in the Burn of Rannas, $3\frac{1}{2}$ miles W.S.W.of Cullen (Read 1923, p. 182). It may also be significant that the Gollachy andesite differs considerably in compactness and scarcity of vesicles from the andesitic lava of the Bogie outlier (Read 1923, p. 181) which contains numerous steam cavities.

The tentative interpretation of the geological situation of the Gollachy Burn andesite given in the foregoing paragraph once again raises the question of the age of the Buckie Beds. If tbe andesite is an intrusion into Cullen Quartzite, and is coeval with andesitic lavas and sediments now thought to be of Lower Old Red Sandstone age (Westoll 1964), e.g. the Rhynie outlier, then the Buckie Beds must be referred to the Middle Old Red Sandstone.

(b) Since the primary Geological Survey of Sheet 95, the small amount of palaeontological evidence which has accumulated suggests that the fish fauna is capable of stratigraphical subdivision. In their work on the Coccosteids, Miles and Westoll (1961, p. 202), have suggested that the replacement of *Coccosteus* s.s. by *Dickosteus* above the Achanarras Band of Caithness is possibly of significance in this connexion. Within the Elgin district the coccosteids collected from the breccia in the Gollachy Burn west of Auchentee (p. 40 above) are identified as *Coccosteus cuspidatus* (Miller *ex* Agassiz MS.) and the same authors have also recognized *Coccosteus* s.s. from the Tynet fish beds (Miles and Westoll 1961, p. 206). The Dipple Fish Bed has, however, yielded *Dickosteus* suggesting that this lies bigher in the succession than the Tynet Fish Bed. This higher horizon is in keeping with the fact that the Dipple Fish Bed lies only a few hundred feet below the base of the Upper Old Red Sandstone.

Conditions of Deposition

The lithology of the Middle Old Red Sandstone, together with the absence of a marine fauna, is strongly suggestive of continental conditions at the time of deposition. Mucb of the material in the conglomerates and sandstones was evidently derived from the Dalradian and Moinian rocks, which at the time probably formed areas of high relief to the east and south. It seems likely that the basal conglomerates were deposited against irregular and locally steep hillsides and are a mixture of colluvial debris and stream gravels derived from no great distance. Higher in the succession the siltstones and nodule beds alternating with sandstones and conglomerates point to the recession of slopes and the supervention of floodplain conditions perhaps not unlike those of tbe River Spey today. The temporary lakes on the floodplain supported a fish fauna, but the occurrences of pellet conglomerates suggest periodic desiccation. J.D.P.

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Chapter V

UPPER OLD RED SANDSTONE

General Account

In the Elgin District, beds referred to the Upper Old Red Sandstone crop out at a number of localities. The largest area in which these rocks are exposed extends from near Forres to the neighbourhood of Elgin. On the coast a limited exposure of Upper Old Red Sandstone rocks is seen west of Lossiemouth, and, inland, strata of Upper Old Red Sandstone age are faulted against Moine Schists south-west of Miltonbrae [175602]. The well-known fossiliferous locality of Scaat Craig lies at the north end of the Glen of Rothes on the east side of the Elgin–Rothes road, a short distance south of the ground described in this account.

For the most part, the Upper Old Red Sandstone strata comprise yellow to reddish brown sandstones, in places pebbly or conglomeratic, with subordinate marly beds and scattered thin seams of clay and shale. Some beds are charged with clay pellets with which are associated isolated bony plates from the dermal armour of fish. In places the sandstones are highly calcareous and at some localities are intercalated with beds of cornstone (concretionary sandy limestone with a little chert).

In subdividing the Upper Old Red Sandstone in the Elgin District difficulties are encountered owing to the extensive drift cover and the sparseness of the characteristic fossils. It was early recognized that the sandstones exposed below the Permian of Quarry Wood, west of Elgin, form a distinct upper division both lithologically and palaeontologically (Traquair 1896). These strata, the Rosebrae Beds, are characterized by the first appearance of *Phyllolepis*. Traquair's (1905) classification was revised by Tarlo (1961) following a detailed examination of the psammosteid fish fauna:

Traquair (1905)	Tarlo (1961)
3. Rosebrae beds	5. (Rosebrae Beds)
2. Alves beds, including the Scaat Craig deposit	4. Scaat Craig Beds
1. Nairn sandstone	3. Alves Beds
	2. Whitemire Beds
	1. Nairn Sandstones

The Nairn and Whitemire beds are not found in the Elgin area.

In a recent study of a wider faunal range, in particular the bothriolepids (Miles, personal communication 1967), it is suggested that the strata at Scaat Craig itself represent a horizon, probably fairly low, in the Alves Beds. This correlation is in accord with the distribution of the Alves and Scaat Craig faunas, most of the former having been obtained from quarries at no great distance vertically below the base of the Rosebrae Beds (Fig. 12), and the latter from near the base of the Upper Old Red Sandstone succession. Thus west of the Rothes Fault diagnostic faunas are confined to the upper part of the succession, and east of it to the lower.

The lithology of the Upper Old Red Sandstone is summarized in Table II. This confirms the distinctive nature of part of the Rosehrae Beds, and suggests the separation of an additional mappable unit, the Cornstone Beds east of the Rothes Fault. Though the Alves Beds and Scaat Craig Beds are not separable lithologically it is considered that both names should be retained. The term Alves Beds is therefore used for those strata west of the Rothes Fault which lie below the Rosehrae Beds and above the Moine schists of Heldon Hill, and Scaat Craig Beds for the succession between the Cornstone Beds and the Middle Old Red Sandstone east of the Rothes Fault.

TABLE II

LITHOLOGY OF THE UPPER OLD RED SANDSTONE

Rosebrae Beds:	Lowest dominantly fine- to medium-grained, compact sandstones of a yellow or yellow-brown colour, with horizons of greenish clay galls; few pebbles; thin marly horizons and shale bands. Higher beds at Findrassie include pinkish brown sandstone with pebbles
Cornstone Beds:	Light grey and reddish brown calcareous marly sandstone with beds of sandy cherty limestone
Alves Beds and Scaat Craig Beds:	Grey, pink, yellow to reddish-brown, fine- and coarse-grained sandstone, often gritty, with pebbles. Some horizons of shale and marl, clay galls. Beds vary from friable to hard and siliceous. Some of the pebbles are faceted

Some features of the Upper Old Red Sandstone are shown in Fig. 12. It can be seen that the northward extension of the Rothes Fault into the Elgin District appears to separate an attenuated succession in the Alves area (where the Cornstone Beds seem to be missing) from a thicker succession to the east. Since beds of Rosebrae type occur on the Knock of Alves at York Tower Quarry [162628] directly overlying the Alves Beds seen lower down the hill, it seems probable that the Cornstone Beds were never laid down on the west side of the Rothes Fault, and that the Rothes Fault was active during Upper Old Red Sandstone times (see below).

The Rosebrae Beds, absent on Carden Hill (Figs. 12 and 13), are about 60 ft thick at the Knock of Alves and from borehole and surface evidence possibly 380 ft thick below the Cutties Hillock (Quarry Wood) sandstone near Oakwood [186628], some two miles west of Elgin. It thus appears that they are progressively cut out westwards by the slight angular unconformity below the Permian and Triassic sandstones, though the angle of unconformity deduced from the above figures is less than two degrees (Fig. 13). In the Geological Survey Spynie Quarry Borehole (p. 131) friable pebbly sandstones and red-brown marly sandstones occur between typical fine-grained Rosebrae sandstone and the Upper Triassic sandstone. These friable sandstones would appear to be the lateral equivalents of the silicified pebbly sandstones resembling parts of the Burghead Beds (Westoll *in* Watson and others 1948) which are exposed south of Findrassie in the same stratigraphical context, i.e. above the Bishopmill sandstone and below the Upper Triassic. The westernmost of the Findrassie quarries seems to be the source of one of Taylor's specimens (Appendix II, p. 136) with a holoptychian plate. Thus in the Findrassie and Spynie areas the highest part of the Upper Old Red Sandstone succession is preserved. From the disposition of the various members of the Upper Old Red Sandstone succession it can be further concluded that most of the movement on the Rothes Fault had ceased before the deposition of the Rosebrae Beds, though a branch of it was apparently again active after Lower Triassic times. These relationships are shown diagrammatically in Fig. 13.

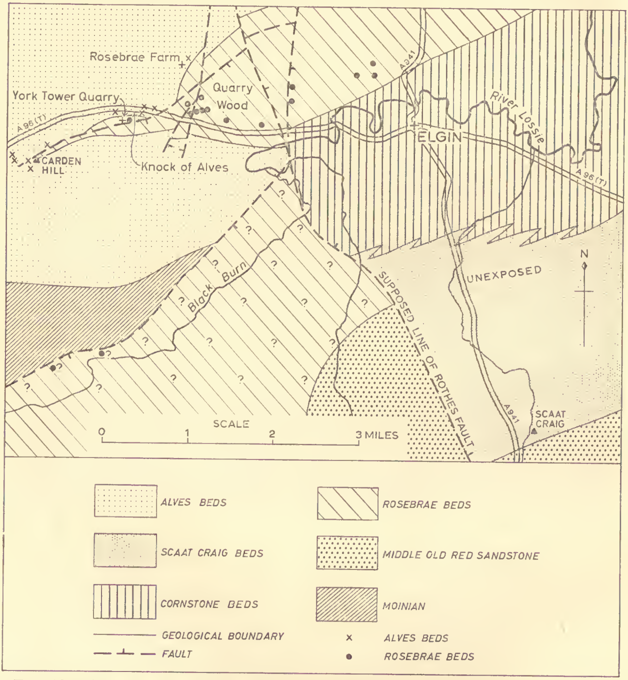

FIG. 12. *Sketch map showing distribution of subdivisions of Upper Old Red Sandstone*

At the edge of and outwith the area covered by the one-inch map, on the south side of Heldon Hill, sandstones similar to the lower part of the Rosebrae Beds (mapped as undivided Upper Old Red Sandstone on the one-inch map), are separated by a fault from Moinian rocks to the north. This fault, the Heldon Hill Fault, appears, like the Rothes Fault, to have moved during Upper Old Red Sandstone times. On the east side of the Rothes Fault the thickness of strata is probably very great, though since the solid rock is almost unexposed the estimated thickness of 4000 ft may be much reduced by concealed faulting.

North of the outcrops of Rosebrae Beds rocks of Upper Old Red Sandstone age are known near Lossiemouth and have been intersected by Geological Survey boreholes at Clarkly Hill near Burghead, at Rosebrae Farm north of Quarry Wood, and at East Mains in the Spynie depression. The strata at Rosebrae Farm have been tentatively correlated with the Alves Beds (Appendix I, p. 133), but the position of the other occurrences within the succession is not known. Boreholes drilled between Hopeman and Inverugie during 1967 intersected fine-grained sandstones of Rosebrae type.

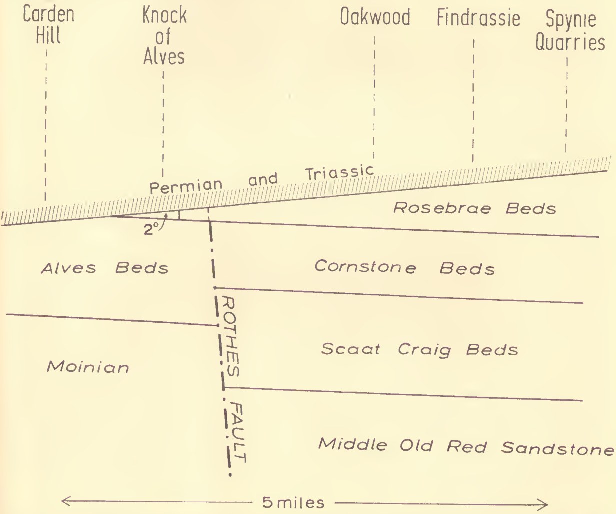

FIG. 13. *Section to illustrate the westward overstep of the Rosebrae Beds below the Permo-Triassic unconformity. Later faults not shown. Not to scale*

The distribution of the Upper Old Red Sandstone in the Elgin area can be summarized as follows:

West of Rothes Fault	*East of Rothes Fault*
Rosebrae Beds	Rosebrae Beds
Alves Beds	Cornstone Beds
(Moine Schists)	Scaat Craig Beds
	(Middle Old Red Sandstone)

DETAILS

Lossiemouth Area. Upper Old Red Sandstone strata are exposed on the shore at Stotfield north and west of the faulted junction with the Trias. They comprise fine- to coarse-grained pink and red sandstones which vary from friable to hard and silicified and commonly have clay galls on the bedding planes. On the reefs of Scarf Craig [229713] grey sandstones also occur, together with a pebbly bed. The true dip of the sandstones is not easy to estimate owing to the well-developed small-scale cross-bedding, but appears to be to the north-west at 5 to 15 degrees. The harder siliceous sandstones adjacent to the fault are characterized by blocky jointing and quartz-lined cavities.

On the golf course [220706] there are a few exposures of silicified sandstone which yielded fish remains during the primary geological survey, and at Cooper's Ditch nearby [216704] the characteristic Upper Old Red Sandstone fossils *Bothriolepis* and *Holoptychius* were recorded. At the Cooper's Ditch locality many of the joint surfaces are coated with colourless to pale brown fluorspar, which also occupies cavities in the rock. In the ditch which crosses the road about 300 yd NE. of North Greens [207705] very soft and friable deep red and white micaceous sandstone is exposed, and on the shore to the north-east there are a few outcrops of the red siliceous sandstone.

South of the outcrop of Trias at Lossiemouth, Old Red Sandstone was formerly seen in one of the housing estates (Westoll *in* Watson and others 1948), and pebbly sandstone exposed at a locality [234705] below the east quarries is probably of Upper Old Red Sandstone age.

Forres to Newton. In the south-west of the Elgin District there are a number of outcrops of Upper Old Red Sandstone, mainly referable to the Alves Beds. For the most part they are grey to pink and red, gritty and pebbly feldspathic sandstones often with galls of red micaceous clay.

South-west of Burgie red sandstone is exposed in an old quarry 300 yd due N. of Easter Lawrenceton [081589] and interbedded pebbly sandstone and conglomerate in a quarry 450 yd WSW. of Burgie House. The unconformable contact with the underlying Moine rocks is seen 200 yd W. of Burgie House [091595], where a knob of Moine quartzite is surrounded on three sides by outcrops, at a lower level, of brown, gritty, pebbly sandstone. Immediately north of the quartzite knob the Old Red Sandstone rocks are grey to buff, fine-grained, feldspathic sandstones which dips away from the contact at the relatively high angle of 36 degrees. In the burn 300 yd NE. of Burgie House somewhat weathered, gritty, yellow sandstone with bands of pebbles and conglomerate occurs, dipping slightly east of north at 10 degrees, and further outcrops of massive, pebbly sandstone with small-scale cross-bedding in places can be followed to the two disused quarries 200 yd ESE. of Burgie Distillery [095603]. North-west of these exposures soft purple shales were visible at one time in the stream 400 yd N. of the distillery, and outcrops of massive coarse gritty pebbly sandstone in an old quarry at Burgie Farm [087601].

In Alves Wood coarse-grained, grey to brown, pebbly sandstone with clay galls was formerly worked at a quarry 920 yd N. 86° E. of Morayscairn [106609], and from here to the Crook of Alves solid rock is probably near the surface, having been at one time exposed in the roadside and in the railway cutting west of Alves Station. About 400 yd due N. of Cloves [138613] a section 8 ft high of pebbly gritty feldspathic sandstone with clay galls and sparse fish remains occurs in an old quarry. Two small faults here trend west-north-west and north-west.

At the west end of Carden Hill siliceous sandstone with scattered pebbles occurs at the surface, and has been quarried at a number of localities. At one of these [140622] an opening shows 12 ft of the usual greyish brown to pinkish pebbly feldspathic sandstone, dipping gently north-north-west, with pebbles up to 2 in across. A little to the south is the Millstone Quarry of Alves [141621] in which similar sandstone with sparsely distributed fish remains and some fine-grained bands was formerly worked to a depth of 20 ft. In the south-west corner of the wood [144621] is a third disused quarry exposing the same rock types. The pebbly sandstone is in part muscovitic and commonly contains galls of red clay on some bedding planes. The pebbles are dominantly of quartzite and psammitic granulite.

Strata of Upper Old Red Sandstone age were formerly extensively quarried south-east of Newton House [162635] though some of the excavations have since been filled in during improvements to the road from Elgin to Forres. About 250 yd W. of Ardgilzean [170633] is the quarry called 'Rosebrae' on the six-inch map, now inaccessible without a rope. This quarry is not to be confused with the Rosebrae Quarry on Quarry Wood Hill. About 50 to 60 ft of rock are exposed, with conglomeratic coarse grit with clay galls resting on gritty pink sandstones. Poorly preserved plant-remains were at one time obtainable from a soft, flaggy layer near the top of the contiguous Newton Quarry a little farther west, and the sandstones have also yielded remains of *Bothriolepis gigantea* Traquair, *Holoptychius nobilissimus* Agassiz, *Psammosteus megalopteryx* Trautschold.

In the southernmost opening of the Newton group of quarries on the south side of the Elgin–Forres road, opposite the junction with the Burghead road, there is a thickness of 100 ft of massive cross-bedded sandstone with conglomeratic and shaly bands near the top.

On the Knock of Alves there is an exposure of about 30 ft of pebbly sandstone in an overgrown quarry at the base of the hill, 400 yd N. 70° W. of the summit, but the upper part of the hill below the Permian rocks is capped by sandstones of Rosebrae type. The quarry at York Tower [162629] exposes 33 ft of fine-grained, buff-coloured, feldspathic sandstone with clay galls, weathering reddish-brown. Small-scale cross-bedding is common together with a few ripple-marked and sun-cracked surfaces.

Pluscarden to Miltonbrae. Most of the strip of Old Red Sandstone rocks on the south side of Heldon Hill lies outside the area embraced by the one-inch map, and the only exposure within the sheet boundary is at Miltonbrae Farm [175602]. Here the conglomerate which forms the foundations of the farm building consists of pebbles and cobbles, up to 9 in across, of psammitic granulite and pelitic schist in a sparse matrix of red grit. According to Taylor (1900) this locality has yielded fish-remains characteristic of the Upper Old Red Sandstone, though on the basis of lithology alone the deposit could be of Middle Old Red Sandstone age. Farther south-west at a locality [151585] 400 yd due N. of Milton Farm, the conglomerate is seen in contact with Moine quartzite. The contact shows a combination of original dip and faulting and it seems likely that the conglomerate was deposited against the scarp of an active fault. There is considerable silicification of the conglomerate here.

South and south-east of the exposures of conglomerate, sandstone of Rosebrae type has been quarried at points 850 yd N. 45° E. of Pluscarden Abbey (where the dip is steep towards the south) and 700 yd N. 60° E. of Milton (Hinxman and Wilson 1902, p. 63). At the former locality the rock is siliceous, pink, white, and brown sandstone with clay galls, and at the latter much softer, massive, white and yellow sandstone, also with clay galls and small-scale cross-bedding. Both quarries have yielded *Holoptychius nobilissimus*, and Mr. P. Brand obtained *Bothriolepis cristata* Traquair and *Glyptopomus cf. elginensis* Jarvik at the Pluscarden quarry, forms typical of the Rosebrae Beds.

Quarrywood to Bishopmill. On palaeontological and lithological grounds the Upper Old Red Sandstone east of the Newton group of quarries described above is referred to the Rosebrae Beds. These were formerly worked for both building stone and road metal, and almost all the exposures described subsequently are in the numerous disused quarries west and north of Elgin.

In Leggat Quarry [176635] about 45 ft of typical pebble-free, brown weathering, fine-grained to gritty sandstone are seen with horizons containing greenish clay galls. Cross-bedding, sun-cracks, and ripple-marks are common, and there are good examples of current lineation on some bedding planes. Scales of *Holoptychius nobilissimus* have been found in the clay gall horizons. Rosebrae Quarry [173633] and another large quarry [177633] expose similar rocks with occasional thin marly seams, and in the latter there is a faulted remnant of basal Permo-Triassic sandstone. In all three quarries, together with a number of smaller openings, Rosebrae Beds are exposed to a total thickness of about 130 ft (ignoring the effects of numerous small faults). Where the beds are undisturbed the dip is at low angles to the north-north-west. At the former Cutties Hillock Quarry a specimen of *H. nobilissimus* was obtained from a shallow shaft sunk through Cutties Hillock sandstone into underlying strata (p. 74).

On the south side of Quarry Wood, further exposures of cross-bedded sandstone with clay galls are seen about 100 yd above the road [180629]. At one outcrop here, there are a few pebbles in the sandstone. About 500 yd NE. of Aldroughty is the well-known Hospital Quarry [188628] which exposes a section of some 80 ft of pebble-free, cross-bedded, grey and yellow sandstone with greenish clay galls and rare thin marly horizons. The quarry is divided into two sections by a prominent north-west trending fault which is accompanied by silicification and crushing. The dip is to the north at about 8 degrees.

On the east side of Quarry Wood, small quarries at Laverockloch and a little farther south [194633] expose typical Rosebrae sandstones, but both openings are much overgrown.

Farther east, exposures of Rosebrae Beds have been extensively quarried at Bishopmill [208638]. Here up to 50 ft of compact grey, cream, yellow, and orange, fine- to medium-grained sandstone are seen, pocked in places by galls of green clay, and carrying sparse pockets, lenticles, and discontinuous bands of pale green marl. The sandstone is strongly cross-bedded, but sparingly jointed, with a general dip of 6 degrees to the north-north-west.

Findrassie. Sandstones resembling the Burghead Beds, but now thought to belong to the Upper Old Red Sandstone, are exposed in a number of old quarries extending westwards from a locality [207652] near Muir of Myreside to the Bishopmill–Duffus road [197644]. The openings are in plantations and are much overgrown. In the easternmost quarry, which is about 200 yd long, a thickness totalling 15 ft of yellow-brown siliceous sandstone can be measured. The pebbly beds, which dip at low angles to the north, are overlain by poorly-exposed, thinly bedded, marly sandstones, possibly of Triassic age. An excavation gave the following section:

	Ft
Sand and rubble	2
Weathered yellowish flaggy calcareous and dolomitic sandstone, brown weathering	2
Reddish-brown, variably-weathered slightly micaceous, flaggy siltstone with thin stripes of pale yellow-green sand. Some carbonate cement	4
Hard, pebbly sandstone	15

Ten yards to the north of this point, a small quarry shows light grey, siliceous Triassic sandstone: an excavation between the two quarries revealed a sharp, probably faulted contact between siliceous sandstone and the weathered yellow-brown flaggy sandstone.

Farther west, at a locality 700 yd N. 85° W. of the cottage at Muir of Myreside [210648] another disused quarry exposes 16 ft of yellow-brown, siliceous sandstone with a few thin pebbly bands, the latter sometimes with a friable silty matrix. Flecks of white kaolinized feldspar are disseminated through the sandstone. The pebbles, which occasionally reach cobble size (6 in) comprise vein quartz, quartzite, and psammitic granulite. In the north-east corner of the quarry the pebbly beds are faulted against light grey, siliceous sandstone, the fault trending east-north-east and dipping steeply north. This fault is evidently the same as that seen in the excavation farther east. However, at a locality [20056495] due west of the above-mentioned quarry a number of excavations show pebbly sandstone, indicating that the faulted contact with the Triassic changes direction towards the west-north-west.

Some 600 yd E. 50° S. of the Mains of Findrassie [194649], there are exposures of pebbly sandstone in a field, and in the neighbouring plantation some much obscured openings show a few feet of yellow-brown, fine- to coarse-grained, laminated and massive, siliceous sandstone with a few pebbles. Some fine-grained bands, more typical at the lower part of the Rosebrae Beds, can also be seen. At a quarry 600 yd E. 81° S. from Mains of Findrassie about 15 ft of grey, pink and reddish-brown sandstone are exposed. The sandstone is mainly fine-grained, but somewhat coarser beds with horizons of clay galls were noted at three localities. A specimen showing a holoptychian scale collected by Taylor, and now preserved at the Royal Scottish Museum (Reg. No. 1965.59.95), can almost certainly be referred to this quarry. A north-easterly trending fault, probably of small throw, can be seen at the quarry entrance.

Elgin and New Elgin to the Boar's Head Rock. The rocks between New Elgin and the coast to the north-east at the Boar's Head Rock comprise the Cornstone Beds, which underlie the Rosebrae Beds of Quarry Wood and Bishopmill. At New Elgin, cornstone is exposed in a quarry [214609] on the golf course. Here there are about 8 ft of pyritous, dark-weathering, light grey calcite mudstone with a little creamy chert, dipping at about 25 degrees to the north. East of the village of New Elgin, in the railway cutting south of Linkwood Cottage [229617], till overlies a few feet of flaggy, pale grey, highly calcareous sandstone and interbedded red marl with clay galls. The dip of the rocks is 15 degrees in a north-westerly direction. In the New Elgin neighbourhood the cornstone was formerly worked at New Elgin [223613 and 222612], Glasgreen [222607], Mayne Wood [213606], and, on the opposite side of the River Lossie, at Pittendreich [196614].

In the Elgin area limestone and sandstone have been penetrated by boreholes and excavations within the burgh, and limestone was formerly seen at Sheriffmills [200631] and Linksfield Quarry [222641] where it underlies a large Jurassic erratic.

Between Elgin and the Boar's Head Rock solid rock is now seen only in the small stream [252613] north of Greens of Coxton, where there are two small exposures of flaggy calcareous sandstone like that at Linkwood. Cornstone was formerly quarried at Waukmill [238623], Nether Meft [272641] and Stonewells [280656]. Large blocks of fine- to medium-grained, calcareous sandstone, speckled with larger quartz grains, are exposed at low tide on the shore opposite the Boar's Head Rock, and on the outermost part of the reef there is sandy limestone and calcareous sandstone with a little chert, apparently dipping at a low angle to the north-north-west.

Redhall Quarry, Fochabers. At Redhall Quarry [341603], a thickness of some 35 ft of interstratified calcareous sandstone, siltstone, shale, and conglomerate is exposed, all of a reddish colour (10 R 5/4–6/6). In the coarser beds the pebbles are well rounded and dominantly siliceous. The sandstones in particular are flecked with spots of kaolinitic material and contain galls of red clay, flattened in the plane of the bedding. Small-scale cross-bedding occurs, the dip of the foreset beds being mainly towards the north-west. The dip of the beds as a whole is also to the north-west, at about 10 degrees, in conformity with the Middle Old Red Sandstone of the Dipple section not far away. Taylor (1900, p. 47) assigned these strata to the Upper Old Red Sandstone and recent work on his collection has shown that *Holoptychius sp.* and *Bothriolepis paradoxa* (Agassiz) occur, the latter characteristic of the Scaat Craig Beds (Miles, personal communication).

PETROGRAPHICAL NOTES

Three specimens (49630–2) collected from the Alves Beds demonstrate some of the salient features of these rocks. They are fine- to coarse-grained, hard sandstones, in part gritty and pebbly, with clay galls, and the colour varies from shades of yellow-brown (5 YR 5/2–10 YR 6/2) to reddish (10 R 6/2). In thin section they are seen to be quartz-sandstones with about 5–15 per cent of fresh microcline and cloudy alkali feldspar, and a little muscovite and biotite. The coarser clastic grains, where present, are commonly of psammitic granulite, altered granite or gneiss, and quartzite, together with a little shale, siltstone, chert and decomposed volcanic rocks. The colour is due to yellow-brown and reddish, limonitic material, but much of the cement is in the form of quartz overgrowths and the original subrounded grains are frequently welded together. Overgrowths of clear alkali feldspar occur on both the fresh and clouded feldspars. A few grains of zircon, tourmaline, and apatite are visible.

Strata lithologically similar to the Scaat Craig Beds and probably of the same age, are exposed at Redhall Quarry, Fochabers [341603]. A brick-red sandstone (49714) consists of about 60 per cent of clastic grains in a largely calcareous cement flecked with reddish iron oxide. The quartz grains (0·4–0·8 mm), which are of moderate sphericity, are commonly angular and corroded, and the feldspar (fresh to decomposed alkali feldspar, some of which is microcline) is also corroded by the cement. Both muscovite and biotite are prominent, together with a few grains of chert and quartzite. Patches of a colourless mineral of the kaolin group and a small amount of fine-grained quartz accompany the largely calcitic cement. The very sparse heavy mineral assemblage includes zircon and rutile. A specimen of fine-grained conglomerate from the same locality (49716) is similar, but contains fragments, up to 3 cm across, of quartzite, psammitic granulite, calcareous siltstone and sandstone, fresh microcline, and angular quartz grains. In a specimen of an interbedded siltstone (49715) quartz (0·01–0·04 mm), muscovite, and possibly a little feldspar are distributed through a groundmass of fine-grained calcite and red-brown ferruginous matter.

Within the Cornstone Beds sandy and silty beds with a considerable proportion of calcite are seen in the Linkwood railway cutting [229616]. The light grey, flaggy rock exposed here (49735) consists of about 50 per cent clastic material (angular and sub-angular quartz with a little fresh microcline) with a grain size below 0·4 mm, enclosed in calcite plates 3 mm across. An interbedded reddish brown, sandy marl (49736) is similar, but contains some muscovite, and the large calcite plates enclose much cryptocrystalline brown material. In the cornstone proper (e.g. 49725–6) from New Elgin Golf Course [215609] rhythmically banded calcite predominates, enclosing corroded sand grains and partly replacing the small amount of chert.

Two sections from the Rosebrae Beds of Leggat Quarry (49627–8) are of fine-grained (0·2 mm), yellow-brown sandstone with about 5 to 10 per cent of feldspar among the clastic material. As in the Alves Beds the quartz grains have a coating of sericite; a section through a green clay gall shows this to consist mainly of a felt of sericite. Of the accessories, zircon predominates, accompanied by a few grains of tourmaline. The rock from York Tower Quarry (49634) [162629], probably in Rosebrae Beds, is much the same, but with an average grain size of 0·4 mm.

Sections from the Upper Old Red Sandstone beds cropping out on the coast west of Lossiemouth are similar to those from Leggat Quarry. A red-brown micaceous sandstone (46862) from Cooper's Ditch [21627042] consists dominantly of quartz grains of variable but generally moderate sphericity and roundness (0·5 mm) with a little feldspar and a few grains of chert and decomposed fine-grained igneous rocks. Much of the cement is quartz, in optical continuity with the sand grains, together with a small proportion of calcite, and red-brown translucent and opaque iron oxides coat many of the grains and occur as discrete spots. In anotber example (51076) some of the quartz grains are welded, and near the fault bounding the Old Red Sandstone outcrop to the east at Scarf Craig [229713] fine-grained sandstones show some replacement of the grains by chalcedony and fine-grained quartz (50174).

Conditions of Deposition

The arenaceous nature of the Upper Old Red Sandstone, the horizons of clay and silt pellets and beds with desiccation cracks, and the occurrence of cornstones suggest deposition under continental conditions. Such conditions were probably dominantly fluviatile by analogy with recent alluvial deposits (e.g. Allen 1965) as is suggested by the occurrence of pebbly, water-laid sandstones, small-scale cross-bedding and current lineation. The occurrences of marly beds, thin clays and horizons with pellet conglomerates support the view that lacustrine (flood-basin) conditions supervened from time to time, the temporary lakes acting as traps for the accumulation of the finer sediments. On occasion the sediments were exposed to wind action, sometimes for sufficiently long periods to allow the faceting of pebbles. The cornstones, which are largely sandstones more or less completely replaced by calcite and chert, are probably similar to the caliche deposits of parts of the U.S.A. (Burgess 1961) and the calcrete of southern Africa (Wayland 1953), both of which are found in areas with a semi-arid climate. Much of the land-surface was probably bare, though there was vegetation in places and a sufficient supply of food to support a varied fish fauna in the lakes and rivers. J.D.P.

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Chapter VI

PERMIAN AND TRIASSIC

General Account

The New Red Sandstone in the Elgin District crops out in two belts, one on the coast between Burghead and Lossiemouth and the other a few miles inland near Elgin (Fig. 14). The following classification is based on the work of Watson and Hickling (1914), Mackie (1925), Westoll (1951), and Walker (1961):

Cherty Rock Sandstones of Spynie, Lossiemouth, and Findrassie	Upper Triassic
Burghead Beds	Triassic
Sandstones of Cutties Hillock (Quarry Wood) and Hopeman	Upper Permian and Triassic

The sandstones of Cutties Hillock (Quarry Wood) west of Elgin have yielded a sparse reptilian fauna of uppermost Permian age, near the Permian-Triassic boundary (Watson and Hickling 1914, p. 2), and in a narrow strip of similar rocks extending west-south-west from Knock of Alves to Carden Hill reptilian remains of the same age have been recovered (A. D. Walker, personal communication). Lithologically similar rocks, the Sandstones of Hopeman, are exposed on the coast between Cummingstown and Covesea Skerries Lighthouse, and cover an area of about 4 sq miles. These deposits, though they have yielded no identifiable fossils apart from reptilian tracks, are believed to be of the same age as the Cutties Hillock (Quarry Wood) sandstone (Watson and Hickling 1914), and some support is given to this conclusion by the striking lithological resemblances, including the suite of heavy minerals (Mackie 1925, p. 161). In a Geological Survey borehole on Clarkly Hill south-west of Burghead, a thickness of 200 ft of beds, equated with the Hopeman sandstone was encountered, resting on Upper Old Red Sandstone (Appendix I, p. 129).

In this account the names given to the two groups of uppermost Permian to Triassic rocks differ slightly from those used in a recent publication (Westoll 1951, p. 18). On the coast the term 'Sandstones of Hopeman' is preferred to 'Hopeman-Cummingstown Sandstone' because Cummingstown village is probably underlain by Burghead Beds. In the Elgin area the name 'Sandstones of Cutties Hillock (Quarry Wood)' is preferred to 'Cutties Hillock Sandstone' because 'Cutties Hillock' is not identifiable on the one-inch and six-inch to one-mile maps of the Ordnance Survey.

The name Burghead Beds (the Burghead Sandstone of Westoll 1951) is applied to a group of sandstones with pebbly bands and occasional silty layers best seen in the neighbourhood of Burghead. To the north, the group is faulted against the Sandstones of Hopeman, and at Inverugie it is overlain by a few feet of sandy, cherty limestone identical with the Cherty Rock overlying the Lossiemouth sandstone. The Geological Survey borehole on Clarkly Hill (mentioned above) showed that the Burghead Beds, some 238 ft thick, pass downwards into aeolian sandstone equated with the Hopeman sandstone, and in view of the

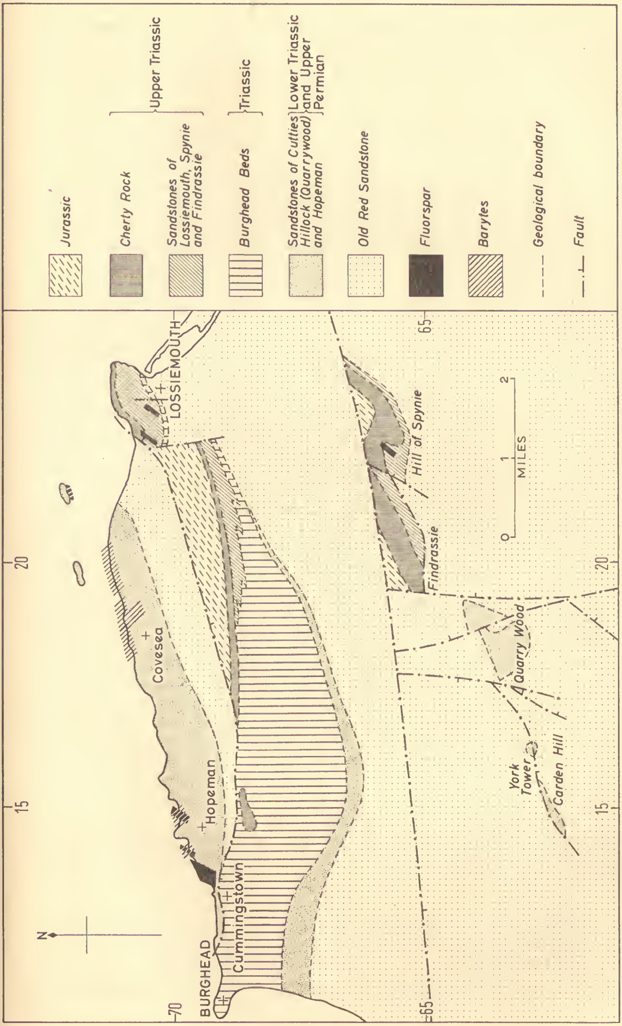

FIG. 14. *Sketch map showing outcrops of Permian and Triassic rocks and distribution of fluorspar and barytes as cement in the sandstones*

position of the latter on the Permian-Triassic boundary, the Burghead Beds may reasonably be regarded as Triassic.

Sandstones, largely aeolian, classed as probably Upper Triassic by Walker (1961) crop out at Findrassie, on the Hill of Spynie, and at Lossiemouth, and thus occur at the eastern ends of the two east-north-easterly trending bands of Permo-Triassic strata. It is possible that rocks of the same age occur elsewhere in the Elgin District hidden by the extensive superficial deposits, but one such occurrence described by Taylor (1920) from near Urquhart seems likely to be a glacial erratic. The thickness of the sandstone at Lossiemouth is probably about 70 ft, and at Spynie about 90 ft down to the level which yielded the first specimen of *Leptopleuron* ('*Telerpeton*') (Murchison 1859). At Spynie the total thickness of strata referred to the Triassic is a little over 100 ft (Appendix I, p. 131). The greatest thickness recorded at Findrassie is 20 ft, but the base is not seen.

Overlying the sandstone at Lossiemouth is a distinctive sandy limestone and chert, the Cherty Rock. Similar rock occurs at Spynie, where it also overlies the Upper Triassic sandstone, and at Inverugie, where it overlies the Burghead Beds. The maximum thickness of this material now seen at any locality is little more than 10 ft, but at Inverugie over 15 ft of cherty limestone were formerly exposed in the old quarries. The Cherty Rock is certainly earlier than Upper Sinemurian in age, since fossiliferous strata of the *Echioceras raricostatum* Zone occur below Lossiemouth Airfield (Berridge and Ivimey-Cook, 1967). The unfossiliferous grits and conglomerates of supposed Rhaetic age in Sutherland overlie marly limestone and chert which have been equated with the Cherty Rock (Judd 1873, p. 142).

The inter-relations of the New Red Sandstone rocks are rarely clear because of scarcity of fossil evidence, the extensive drift cover, and the lack of marked lithological differences. There is also little to differentiate the Burghead Beds from parts of the Old Red Sandstone succession, a difficulty which is underlined by the lack of knowledge concerning the latter. From the Geological Survey Clarkly Hill Borehole, there is now reasonable evidence that the Burghead Beds overlie the Hopeman sandstone, and that the latter rests on Upper Old Red Sandstone. At the east end of the belts of New Red Sandstone at Lossiemouth and Spynie, however, the beds below the known Upper Triassic appear, on balance, to be Old Red Sandstone in age rather than New Red Sandstone, although the evidence from the Geological Survey Borehole at Spynie Quarry is not conclusive (Appendix I, p. 131). Further evidence bearing on the age of the beds below the Upper Triassic sandstone comes from the Findrassie area where silty calcareous strata, similar to those occurring below the presumed reptiliferous horizon at Spynie (p. 131), rest on siliceous sandstone with pebbly horizons and sparse lines of clay pellets. The siliceous sandstones here seem to have yielded fish remains at one time (p. 51) and thus in spite of a considerable lithological similarity to the Burghead Beds, must now be taken as being of Upper Old Red Sandstone age. The succession at the east end of the New Red Sandstone outcrops is therefore:

Aeolian sandstone Pebbly sandstone (Lossiemouth) Water-laid silty calcareous beds	Triassic (probably mainly Upper Triassic)
Pebbly sandstone	(Upper Old Red Sandstone)

The very thin pebbly sandstone at Lossiemouth may be representative of the

Burghead Beds, which together with the Sandstones of Cutties Hillock (Quarry Wood) and Hopeman seem to die out rapidly towards the east. It is possible that the Burghead Beds, which are water-laid, are in part coeval with the sandstones of Spynie, Lossiemouth and Findrassie.

Sandstones of Cutties Hillock (Quarry Wood) and Hopeman

Sandstones of Cutties Hillock (Quarry Wood)

The upper part of Quarry Wood Hill, some third of a square mile in area, is occupied by a thin capping of yellow-brown sandstone varying from hard and siliceous to soft and somewhat friable. Like the similar Hopeman sandstone it is characterized by large-scale cross-bedding which hinders recognition of the true dip, though the geometry of the outcrops suggests that the formation is in fact dipping northwards at a very low angle. At the base there are a few feet of rather structureless sandstone with numerous pebbles, some of which are clearly ventifacts, possibly slightly rounded by water action (Mackie 1901). A second strip of hard, siliceous, grey sandstone with a pebbly base, extending from the Knock of Alves to Carden Hill has recently yielded fossil material confirming an uppermost Permian age (Walker, oral communication) at Knock of Alves. The greatest thickness of the Cutties Hillock (Quarry Wood) sandstones is probably between 100 and 150 ft.

In the Quarry Wood area the Cutties Hillock sandstones are known to lie with slight angular discordance on the Rosebrae group of the Upper Old Red Sandstone, but at Carden Hill they rest on the lower Alves Beds. Between these two localities, at Knock of Alves, the Cutties Hillock sandstones lie apparently conformably on Rosebrae Beds, but the latter can be of no great thickness because Alves Beds occur towards the bottom of the hill.

The disposition of the Cutties Hillock sandstones is probably partly the result of faulting. At Rosebrae Quarry a small patch of these strata faulted against Old Red Sandstone is based at about 212 ft O.D. compared to 313 ft O.D. for the main mass of the Cutties Hillock sandstones nearby. At Knock of Alves (York Tower) Quarry the base lies at about 210 ft. O.D. south of a small disturbance and 248 ft O.D. north of it, and the line of unconformity gradually rises west-south-westwards to near 270 ft O.D. on Carden Hill. Thus it seems likely that the greatest displacement in the Cutties Hillock sandstones, of the order of 100 ft, occurs between Rosebrae Quarry and the ground immediately to the east. This fault, though nowhere exposed, must run in a direction near north-south.

Details

The easternmost exposure of the Sandstones of Cutties Hillock (Quarry Wood) is seen in an old quarry 400 yd NW. of Laverockloch Farm [193637] opened since the primary geological survey in 1878. Here a thickness of about 35 ft of 'millet-seed' sandstone, somewhat weathered and shattered, especially towards the top, is overlain by 5 to 12 ft of till. The bottom of the quarry is at 277 ft O.D.

Next along the ridge, within Quarry Wood itself, is the old Millstone Quarry, situated 500 yd ENE. of the hill-top at a height of about 390 ft O.D. The history of this quarry is described in detail below (p. 73), it being the same as the 'Cutties Hillock' quarry of the literature. It was at this locality that most of the reptile fauna of uppermost Permian age was obtained. Exposures of coarse yellow sandstone with joints mineralized with barytes and hematite are still visible. From the old accounts the base of the New Red Sandstone here is not far below the present floor of the quarry (354 ft O.D.) and it seems probable, therefore, that a fault lies between it and the quarry described in the previous paragraph.

South of the Millstone Quarry of Quarry Wood there are a number of glaciated exposures of hard sandstone, now much overgrown, extending almost as far as the 'Danish Camp'. The summit of Quarry Wood Hill (the original Cutties Hillock) is formed of glacially striated, hard, gritty, dune-bedded sandstone with a few pebbles, formerly quarried at points 150 yd SE. and 100 yd WSW. of the triangulation station. The more easterly quarry may be the site of the footprints found by Watson and Hickling (1914). A prominent fault trending a little east of north can be seen in the other quarry.

West of the 'Danish Camp' sandstone was formerly worked in two small quarries [18306295, 18206293]. The latter quarry was excavated to a depth of 20 ft at the time of the primary survey.

Below the main outcrop in Quarry Wood a small patch of Cutties Hillock sandstones is let down against Rosebrae Beds by a north-east-trending fault in Rosebrae Quarry [173633]. It consists of a little over 12 ft of friable, pebbly sandstone resting with a slight unconformity on Rosebrae Beds, the contact dipping at 6 degrees towards N. 15° E. The pebbles, which are randomly distributed, sometimes take the form of wind-faceted dreikanters with rounded edges suggestive of re-working, though no cross-bedding can be seen apart from a suggestion of the large-scale possibly dune-bedding visible elsewhere in the Permian. The pebbles are mainly of quartz and metamorphic rocks, together with a few of sandstone.

West of Quarry Wood the Cutties Hillock sandstones are next seen on the Knock of Alves where they have been quarried both north and south of the summit. The north quarry, little more than a trial pit, is almost completely overgrown but a few blocks of the sandstone are visible at the bottom. The south quarry, known as the York Tower Quarry, has been excavated through talus into the solid rock, and in the southern part the quarry floor is above, but within a few feet of the base of the Cutties Hillock sandstones. About 30 ft of hard, white, siliceous sandstone are exposed, becoming pebbly towards the bottom. The skull of a dicynodont-like reptile was recently found by Dr. A. D. Walker in the east face of this part of the quarry, about 5 to 10 ft above the quarry floor. The north face of the quarry lies parallel to a fault separating the New Red Sandstone on the south side from 33 ft of Rosebrae Beds capped apparently conformably by a few feet of pebbly Cutties Hillock sandstones. Both the York Tower Quarry and the small northern excavation have been opened since the primary geological survey of the eighteen-seventies.

Carden Hill is surmounted by a fine, glaciated pavement of hard, white, siliceous sandstone which appears to be a continuation of that exposed at the Knock of Alves. Here the strip of Cutties Hillock (Quarry Wood) sandstones appears to rest directly on Alves Beds on the south side of the hill (though the contact is not seen), and to be faulted against Alves Beds to the north.

SANDSTONES OF HOPEMAN

The yellow to buff coloured sandstones which form the majority of the coastal Permo-Triassic rocks crop out from Cummingstown in the west to a point east of Covesea Skerries Lighthouse. Here a distance of about 250 yd separates the last exposures of Permo-Triassic sandstone from the Upper Old Red Sandstone exposed on the foreshore. Though unexposed, the contact between the two rock groups in this neighbourhood is thought to be an unconformity. Near

Cummingstown, however, the Hopeman sandstones are faulted against Burghead Beds, but for the most part the southern contact with neighbouring rock formations can only he inferred on somewhat slender evidence.

Many of the Hopeman sandstones are laminated to a greater or lesser degree, and are composed of well-rounded grains of quartz and feldspar often of high sphericity, with only a little mica. These characteristics, taken in conjunction with the large-scale cross-bedding, are suggestive of dominantly aeolian deposition and the deposit is generally regarded as a dune-hedded sandstone (Westoll in Watson and others 1948, Shotton 1956). At one locality, however, there is a small thickness of water-laid pebbly sandstones, and some of the large foreset heds elsewhere show evidence of water action in the form of small-scale cross-hedding. In addition, the foreset heds are frequently modified by penecontemporaneous movements which have produced hasin and dome structures, fold lobes and blisters, and local brecciation (Peacock 1966). The thickness of the Hopeman sandstones is some 200 ft in the Geological Survey horehole on Clarkly Hill and probahly diminishes from west to east.

As mentioned above, the Hopeman sandstones have yielded few traces of fossils. Reptile footprints were formerly common at the now long-disused Masonhaugh Quarries [125692] and have been observed from time to time on other parts of the coast, particularly in Greenbrae Quarry [137692] near Hopeman (where they are known as 'rahhit footprints' hy the quarrymen), and more recently at Clashach Quarry [163702] (p. 61). Watson and Hickling (1914), after a study of the prints here and at other localities, concluded that an Upper Permian age was confirmed, hut this type of evidence would now he regarded with reserve. That the rocks are not otherwise completely unfossiliferous was confirmed during the revision survey when a small unidentifiable fragment of bone was found at Greenbrae Quarry. It is of interest that much of the fossiliferous material at Cutties Hillock appears to have come from near the base of the formation, and it may he that the absence of exposures of this part of the succession on the coast accounts for the apparent lack of fossils.

Details

Between Masonhaugh and Cummingstown the Hopeman sandstones are confined to the coast and are separated from the Burghead Beds to the south by a fault. At its first appearance on the shore west of Masonhaugh Quarries the sandstone is extensively silicified and forms an upstanding reddish mass which contrasts with the less cemented Burghead Beds south of the fault. The cross-bedding from here to Greenbrae Quarry is generally inclined between south-west and south, and at the first appearance of the Hopeman sandstones at the west end of the section a unit of cross-bedding over 600 yd long and 70 ft thick can be seen. North of Masonhaugh Quarries the brownish yellow sandstone on the shore is relatively soft and friable and this type of rock continues to Greenbrae Quarry. Joint and shear planes along which silicification has taken place give rise to narrow dyke-like masses which stand above the wave-cut platform of the softer sandstone.

In Greenbrae Quarry the main working face at the south side, some 50 ft high, is formed of two (possibly more) almost parallel cross-bedded units dipping some 20 degrees south-south-west. The sandstone is a fine- to medium-grained variety, yellow-brown in colour, which hardens somewhat on exposure to the atmosphere. It is finely-laminated in places and shows a few ripple-marked surfaces on the cross-bedding planes, and small cut-and-fill structures. A little to the north a disused part of the quarry shows beds with scattered small quartz pebbles; one of these beds yielded a small fragment of bone.

In the north part of Greenbrae Quarry and on the neighbouring coast the sandstone shows patchy cementation by fluorspar. In some places the cementation is in the form of well-scattered cubes of fluorspar, which gives a spotted appearance to the rock; in others these coalesce to form 'reefs' of hard sandstone which are more resistant to weathering and marine erosion. Some of the 'reefs' tend to be elongated in a north-south direction, and may also be roughly parallel to the bedding, as mentioned by Wilson and Dunham (*in* Dunham 1952, pp. 125–7). The fluorspar-bearing sandstone, which does not appear in sufficient quantity to form workable posts, is discarded by the quarrymen, and the best specimens can usually be obtained from the quarry waste.

On the coast north of Greenbrae Quarry, between tidemarks, there is a development of concretionary sandstone at two points (Plate IIIB). At the more westerly [13786952] there can be distinguished: (a) sandstones in which the cement is in the form of ferruginous concretions; (b) sandstones in which the cement is in the form of calcareous concretions surrounded by sandstone with a ferruginous cement.

At the more easterly [13876955] both (a) and (b) occur with fluorspar nodules, the distribution of which is independent of the concretions. Fluorspar also occurs in the shear planes which cut the concretions (p. 62).

From the concretionary sandstone locality to a point 400 yd W. of the harbour at Hopeman there are a few 'reefs' of fluorspar, some of which are not surrounded by the usual 'halo' of white spots. East of this there are numerous nodules, laminae and 'reefs' of barytes-cemented sandstone, and at one locality blebs of spherulitic pink barytes were noted. These rocks also show fine examples of disturbed bedding—vertical dips, basins and domes, blisters, and sandstone breccias—and the ferrugious cement is sometimes concentrated in 'Liesegang Rings' which cross-cut the bedding. All these various structures, together with local close-jointing along which the sandstone is in places silicified, are foci for the growth of laminae and nodules of the barytes cement. The westward limit of barytes is sharply defined, and all the various structures crossing it lose their mineralization at about the same point. The 'reefs' of fluorspar within the area with dominant barytes cement are usually discrete, but the surrounding 'halo' of fluorspar cubes may overlap with the nodules of barytes.

At the east side of a small quarry, 400 yd WSW. of the pier, a few quartz pebbles up to 2 cm across occur in the rock. The disposition of the barytes 'reefs' in this neighbourhood is such as to give the appearance of a breccia of barytes-cemented sandstone in soft friable sandstone, thus adding to the already complex structures.

East of Hopeman harbour the coast section shows rather friable sandstone in which the coarser laminae are often cemented with barytes and resist weathering in characteristic fashion. In the middle of the bay there are spots and 'reefs' of fluorspar as well as barytes, but the north end of the beach coincides approximately with the eastern limit of barytes-fluorspar mineralization in this neighbourhood. North of the beach for a few hundred yards there are good examples of the contorted bedding, with blister folds, brecciation and sandstone in which bedding structure has disappeared. Near the point where the coast swings from a north-east to an east-south-easterly direction, some 1100 yd from the harbour at Hopeman, the eroded top of a disturbed bed is unconformably overlain by an undisturbed north-westerly-dipping unit of water-laid, ripple-marked sandstone with pebbly beds and a few laminae of greenish silty clay. This occurrence [15507035] is convincing evidence of the penecontemporaneous nature of the contortions. The water-laid bed is itself overlain by another dune-bedded unit with penecontemporaneous drag folds and imbrication (Peacock 1966, p. 159). At one locality [15607034], just north of an old quarry, the oblique contact between normal dune-bedded sandstone and disturbed beds is marked by a 1- to 4-ft horizon of massive sandstone containing fragments of bedded sandstone.

The coast between the headland [156703] and the bay with the cave called Sir Robert's Stables [174707] is relatively free of bedding disturbance and is mainly formed of carious-weathering, soft, brownish yellow sandstone in places blackened and hardened by superficial ferruginous cement. Cementation structures simulating the contorted beds are fairly common and a good example can be seen just north of the Gipsies Cave [160702]. The fault along which the Gipsies Cave has been eroded has a throw of at least 10 ft to the south and can be traced westwards some 500 yd into an old quarry. In the Gipsies Cave the north face of the fault is well seen, with slickensides plunging 70 degrees towards the west.

In Clashach Quarry [163702] stone almost identical with that from Greenbrae Quarry is currently wrought. The main face, about 100 ft high, is formed of one set of cross-bedding in which the dip is 20 degrees towards the west-south-west. Much of the rock is massively bedded, medium- to coarse-grained sandstone, grey to yellow-brown in colour, containing scattered quartz pebbles (1 in across) near the bottom of the quarry. Some of the lower courses of stone are blemished by ferruginous spots, and many of the joint surfaces are stained by iron oxides. Higher up the face the rock varies from soft to hard and siliceous. Poorly preserved reptilian footprints were noted on a slab above the main face.

Some 650 yd along the coast is the disused Covesea Quarry [16907035] in which somewhat weathered massive yellow sandstone is exposed. The 50-ft high face appears to be all one unit of cross-bedding. Just north of this quarry is a 100-ft high cliff showing contortions above undisturbed cross-bedding (Plate I, Frontispiece). About 300 yd W. of Sir Robert's Stables, a small disturbed bed can be seen in the cliff to be overlain by undisturbed dune-bedding [17877083].

From Sir Robert's Stables to the bay east of the hamlet of Covesea there are good exposures of dune-bedded sandstones in which contorted bedding is common. Some of the sandstone laminae are cemented by barytes. North of Easter Covesea the post-Glacial raised beach cliff is partly covered by blown sand, but intermittent exposures show sandstones similar to those described above. About 300 yd west of Covesea Skerries Lighthouse there are some fine examples of lobate folds accompanied by penecontemporaneous breccias. The sandstone fragments in the breccias, up to 6 in across, commonly weather more easily than the almost structureless matrix, giving the rock a pitted appearance. Below the lighthouse there are considerable exposures of almost unbedded sandstone containing scattered fragments of bedded sandstone. Later cementation by irregular nodules and veins of bartyes in this area obscures many of the primary structures and contributes to the fretting of surfaces exposed to sub-aerial weathering.

On Halliman Skerries well-jointed, partly silicified, greyish-orange sandstone stands a little above high-tide level. Between tide marks on the south side of the Skerries are numerous boulders of softer sandstone, many of which are spotted with nodules of fluorspar and barytes.

In addition to the fine coastal sections of the Hopeman sandstone, similar sandstones are exposed at a few old quarries on the higher ground of Covesea Hill. A largely filled-in scraping 350 yd NE. of Burnside [169697] still exposes about 4 ft of buff-coloured, thinly-bedded sandstone with numerous weathered-out clay galls. Normal yellowish 'millet-seed' sandstone is exposed in nearby quarries, one of these, 750 yd W. of Wester Covesea, being excavated to a depth of about 20 ft in yellow to yellow-brown sandstone.

Petrography

Sandstones of Hopeman

The Hopeman sandstones comprise even-grained and laminated sandstones which at a few localities contain quartz pebbles. Even-grained sandstones at present quarried at Greenbrae and Clashach have a grain size of 0·3 mm. In the laminated sandstones (46978) [18147092] the sand-grains in the coarser laminae reach 1 mm in diameter. Of the clastic grains, by far the most abundant mineral in four specimens from Greenbrae Quarry (46835–6, 46838, 46843), is quartz, with about 5 per cent of feldspar and smaller quantities of chert. The remaining clastic materials in these specimens include metamorphic quartzite, vein quartz, psammitic granulite, fine-grained sandstone, myrmekitic granite, hornfels, and a flake or two of muscovite. Where not modified during diagenesis the individual grains are well-rounded and of high sphericity. Most of the feldspar is fresh microcline, but there is invariably a percentage of dusty, untwinned alkali-feldspar, some crystals of which are crowded with specks of limonite. Secondary quartz, in places forming euhedral outgrowths, yellow-brown to red-brown, birefringent iron oxide, and leucoxene, are the chief cementing materials, the iron oxides occurring as discrete spots and as pellicles around the quartz grains. Secondary growths of feldspar on feldspar are not uncommon. Some of the sandstones, however, are only partially cemented, leaving a large amount of pore space. Heavy minerals are scarce, and are largely confined to zircon and tourmaline, though rutile, garnet, anatase, leucoxene, magnetite, haematite, and traces of corundum, kyanite and amphibole were noted by Dunham (1952).

In specimens from the area of silicified sandstone north-west of Masonhaugh Quarries (46855) [12266914], (46856) [12376912], some even-grained clastic minerals with diameter about 0·5 mm are present, retaining traces of overgrowths of quartz and feldspar, but angular fragments predominate. The percentage of chert and quartzite fragments is small, possibly because of recrystallization during silicification. The sandstones immediately adjacent to many of the steeply dipping joint and shear planes are silicified at a number of localities, and a slice from one such occurrence in Greenbrae Quarry (48800) [13786914] shows normal sandstone through which pass thin bands of comminuted quartz cemented by fine-grained quartz and chalcedony.

The distribution of sandstones cemented by barytes is shown in Fig. 14. In the laminated sandstones (46978) [18147092], the barytes is in the form of large plates confined to the coarser-grained laminae, but elsewhere it gives rise to nodules of varying shape which are either separate or coalescent. The sand grains in the nodules in places retain their shape and their outgrowths of secondary quartz (48802) [14557003] but at other localities show varying degrees of replacement by barytes (46863) [18857100]. In one specimen (48805) [14146975], barytes has completely replaced the sandstone. Mackie (1901, p. 650) gives an analysis of 37 per cent of barium sulphate in a nodule.

Where fluorspar is present in the Hopeman sandstones as a cementing substance (Fig. 14), it commonly occurs as scattered cubes less than 1 cm across which in places coalesce to form small irregular bodies of yellowish grey sandstone with a bluish tinge (Dunham 1952, p. 126). In section (46837) [13716931] the clastic grains are partly isolated by the fluorspar and the secondary overgrowths which occur in fluorspar-free areas are absent.

On the shore north-east of Greenbrae Quarry sandstone with calcite concretions and spots of fluorspar is exposed immediately below high-tide mark (p. 60). The corroded clastic grains lie in a sparse cement of euhedral 'poikilitic' fluorspar cubes around which the calcite of the concretions is moulded (46842) [13876955]. It is considered that, as the distribution of fluorspar is independent of the calcite concretions, the growth of fluorspar in an uncemented rock probably predated the growth of the calcite concretions. Since the concretions are cut by shear planes along which a little fluorspar replacement has taken place (48808) [13876955], there is support for the view that there were at least two episodes during which fluorspar was deposited locally, the growth of the concretions and the shearing having taken place during the interval.

SANDSTONES OF CUTTIES HILLOCK (QUARRY WOOD)

Sandstones from Quarry Wood Hill compare closely with the Hopeman sandstones. Two specimens from the summit of Quarry Wood Hill (49625–6) are similar to the silicified sandstone on the coast north-west of Masonhaugh Quarries, described above. In laminated sandstone from a nearby quarry (49629) [17956355], the grain-size varies from 0·4–0·5 mm in the coarse laminae to 0·1–0·2 mm in the finer-grained laminae, and there is an increase in angularity with decreasing grain-size.

CONCLUSIONS

The sandstones fall within the protoquartzite group of Pettijohn (1957). The low percentage of heavy minerals and micas, together with the shape of the clastic grains, support the view that they were deposited by wind. Some compaction with concomitant formation of overgrowths on the sand grains apparently took place before the incoming of the relatively sparse cement of barytes, fluorspar, and silica. At one locality it is suggested that fluorspar mineralization took place during two phases separated by the growth of calcite concretions and by movements on shear planes. The relationship of the cementing substances to the galena-fluorspar-barytes mineralization in faults and in disseminations (p. 125) has not been directly ascertained, though there is probably a genetic connection.

BURGHEAD BEDS

The Burghead Beds crop out on the coast at and near Burghead, and are also seen between Clarkly Hill and Inverugie.

DETAILS

Roseisle district. Pebbly sandstones dipping gently northwards are exposed on the shore between Burghead and Masonhaugh and at a few points inland farther east as far as Cummingstown. At the west end of the harbour at Burghead a good section is seen of about 12 ft of strongly cross-bedded, little-jointed, fine- to coarse-grained sandstone with a few thin silty beds and lines of silt galls. Pebbly layers are common, some beds being almost conglomeratic. Among the pebbles reddish quartzite is common, with smaller amounts of psammitic granulite, vein quartz, and gritty sandstone. A small washout-channel is seen, and the cross-bedding in this and adjoining beds generally dips north-east. Similar sandstone about 25 ft thick is exposed in the cliff north of the harbour, where some of the pebbly bands approach 4 ft in thickness. Desiccation cracks were seen at one point during the primary survey. The beds vary from hard and well cemented to friable with varying proportions of siliceous, and in some parts calcareous, cement. Below the Coastguard Station the rock is broken by a small fault, and large sandstone blocks, bounded by joint faces and bedding, litter the foreshore.

North of Burghead, sandstones similar to those described above are well seen between tide marks dipping gently north. These [10836913] are overlain north-east of the Coastguard Station by a few feet of highly calcareous sandstone with scattered larger quartz grains and small quartz pebbles. The calcareous strata can also be seen at the 'Roman Well' [11026915] in Burghead Village, in the old railway cutting [12276911] north of Masonhaugh, and on the shore adjacent to the fault separating the Burghead Beds from the Hopeman sandstone. A number of small silicified shear planes like those in the Hopeman sandstone occur in the wave-cut platform.

East of Masonhaugh the shore section is entirely in Hopeman sandstone, but Burghead Beds occur at the west end of Masonhaugh Quarry, at Roddoch Wells [132692] and the adjacent railway cutting north of Cummingstown, and at Cabrach How 100–200 yd to the east of Roddoch Wells where they crop out in the cliff of the post-Glacial beach. These rocks are similar to the Burghead Beds exposed at Burghead. At the small bridge [13226912] crossing the railway south of Roddoch Wells, a section adjacent to the bridge on the south side of the cutting shows 16 ft of yellow to ochreous sand and silt with impersistent seams of coarse ferruginous sand in the upper part and occasional lenticles of friable sandstone throughout. Near the top of the section, which is overlain by till, is a 6-in bed of pale yellowish grey clay. Immediately east of the bridge these beds can be seen resting on pebbly sandstone and can be traced to Cabrach How where they are in turn overlain by pebbly sandstone.

Quarrying has exposed pebbly sandstone belonging to the Burghead Beds at several points on Clarkly Hill, south-east of Burghead. About 400 yd SE. of the Transmitting Station [125686] two old quarries are excavated into about 12 ft of strongly cross-bedded, coarse-grained sandstone with bands or lenticles containing small pebbles, dipping at 7 to 8 degrees to the north. Some 300 yd to the east of these localities, a much-obscured quarry [13036838] on the main summit of the hill shows only small exposures of fine-grained, yellow, siliceous sandstone, though at the time of the primary survey up to 12 ft of calcareous sandstone mineralized by fluorspar and galena could be seen. These strata evidently overlie the pebbly sandstone cropping out farther west and may equate with the highly calcareous sandstone seen on the shore.

Though rock is not exposed on the ridge running eastwards from Clarkly Hill it is probably at no great depth and reaches the surface in the Inverugie area south of Hopeman where it has been quarried at several points. Just south of the summit of Gallow Hill [147685] a quarry face is formed of some 20 ft of sandstone, and 200 yd WSW. of the summit another small opening [14516838], at a lower level, shows a few feet of pebbly sandstone. The succession, which dips gently to the north, is as follows:

		Ft
4.	Sandy cherty limestone and chert (Cherty Rock)	11
3.	Hard, reddish, massive, fine-grained, siliceous sandstone with scattered larger quartz grains. A few clay galls and cavities with quartz and galena near the top. Grades downwards and laterally into: grey, medium-grained, massive, calcareous sandstone with scattered larger quartz grains and a few pebbles	23
2.	*Gap*	15
1.	Dark, yellow-brown (10 YR 5/2), siliceous sandstone with pebbles of reddish quartzite and vein quartz and fragments of kaolinized feldspar	7

The upper beds continue eastwards in a highly-weathered condition through a few small disused quarries to a point 100 yd WNW. of Inverugie House [15226855]. A succession very similar to the above was found in a bore at St. Peter's Well, Duffus [17206874] which gave the following section:

		Ft	in
	(Superficial deposits)	20	6
	Sandy cherty limestone	5	0
d.	Fine-grained brown to slightly greenish siliceous sandstone	2	0
d.	Compact brown calcareous sandstone	4	6
d.	Brown to reddish-brown massive fine-grained sandstone, in part with scattered quartz grains	14	0
d.	Hard fine-grained sandstone with occasional large quartz grains	5	0
c.	Fine-grained brown and grey sandstone, broken at top. Steeply-inclined bands of black staining	10	6
c.	Pebbly sandstone, quartz pebbles up to ¾ in, in a brown, sandy matrix	1	3
c.	Dark red sandstone with vertical bands of black staining. Thin bands of ½-in quartz pebbles	2	6

		Ft	in
b.	Pink and brown hard pebbly sandstone, pebbles up to 2 in ..	21	9
a.	Well-bedded yellowish brown sandstone, medium- to coarse-grained, with partings of greenish sandy shale at top ..	8	4
	Sandy shale, yellowish brown, micaceous		2
	Yellowish to pinkish brown, well-bedded sandstone with pebbly bands, soft in part	14	0
	Pebbly sandstone	16	6

Bed 1 at Inverugie evidently equates with (b) at Duffus, and 3 with (d).

On the south side of the Hill of Roseisle a partly overgrown quarry [15166690] above the road some 500 yd E. of the Bank of Roseisle exposes 20 ft of pale yellow-brown, siliceous sandstone, rather massive, with gritty beds and scattered pebbles up to 3 in across. Near the top of the quarry is a band of yellow siltstone a foot thick. There are traces of another old quarry 400 yd to the north-north-west which formerly exposed soft yellow sandstone.

Other localities. On the south side of the hill at Lossiemouth the beds below the east quarries (Triassic) are exposed in the old post-Glacial sea-cliff, now much modified by housing development and quarrying. At a point 400 yd N. 85° E. of the school [233705] there is a section some 15 ft high of alternating thinly-bedded, yellow and pink sandstones dipping gently north-east. Sets of cross-bedding vary from about 9 in thick to 1 in towards the top. Some micaceous siltstones occur together with gritty bands and lenses with small quartz pebbles. Some of the beds are strongly colour-banded and calcareous, with lustre-mottling. The bottom 2 ft is a hard micaceous siltstone, and the succession grades upwards into massive siliceous sandstone. A poorly-exposed section on the north side of a fence surrounding a recently erected block of flats [23547065] some 180 yd WSW. of the above and 15 ft vertically below it shows 2 ft of yellow-brown, pebbly sandstone identical with material from a similar horizon in the Spynie Quarry Borehole (p. 131) and is doubtfully referred to the Old Red Sandstone.

Petrography

From Burghead to Cummingstown, the Burghead Beds are mainly pale yellowish brown to greyish orange (10 YR 7/4 to 10 YR 6/4) and range from coarse-grained pebbly sandstones with prominent red and white quartzite pebbles, through gritty sandstones to greenish yellow siltstones and, rarely, clay. Some beds are friable and others well cemented with silica or carbonate.

In thin section, three specimens collected on the shore [11926910] are inequigranular (commonly 0·3–1·0 mm), the clastic grains consisting dominantly of quartz, with about 5 per cent feldspar (fresh microcline and untwinned alkali-feldspar), and scattered grains of metamorphic quartzite, granular quartz, strained vein quartz and chert. A few flakes of muscovite occur (46859), and some spherical blebs of leucoxene. The cement may be secondary quartz or chalcedony, or small plates of calcite partly enclosing the clastic grains (46860). Some packing of the quartz grains has undoubtedly occurred, bringing the grains into contact at many points. A few calcite spherulites (0·5 mm) with radial structures are to be seen in one section (46860). Heavy minerals are confined to one or two grains of zircon, tourmaline and apatite.

Highly calcareous sandstones with disseminated, larger well-rounded quartz grains and small pebbles overlie the beds mentioned in the foregoing paragraphs near low-tide mark north of Burghead (46834) [11096928], at the 'Roman Well', and at various points near the faulted contact with the Permian (46833) [12066919]. The impression of two distinct grain-sizes is maintained in thin section where the larger grains (0·5–1·5 mm) are of well-rounded quartz, often with a high sphericity, together with quartzite, strained vein quartz, calcareous sandstone and chert. The matrix of the rock is an even-grained sandstone (0·2 mm) with a little calcite and untwinned potash feldspar in addition to sub-rounded to angular fragments of quartz, chert, and a few possibly clastic spots of hematite and leucoxene. The cement is largely granular or platy calcite. Heavy minerals are somewhat less sparse than in the underlying rocks, zircon, tourmaline, rutile? and epidote? having been noted. There are one or two indications of organic structures in the calcite.

On Clarkly Hill the highest sandstones of the Burghead Beds appear to be almost free of pebbles. A specimen from an almost completely filled-in quarry at the top of Clarkly Hill (46840) [13036838] is of fine-grained, pale yellow sandstone (5 Y 7/2) which in thin section shows very scattered, larger well-rounded quartz grains (up to 1 mm) grading into fairly even-grained clastic material (0·1–0·4 mm) of varying roundness and sphericity. About 20 per cent of fresh microcline and a little untwinned, cloudy alkali feldspar accompanies the quartz, and there are also a few grains of chert. Much yellow-brown and red-brown iron ore is disseminated through the cement (mainly secondary quartz and chalcedony), and pellicles of iron oxide coat the clastic grains. The suite of beavy minerals includes zircon, garnet, tourmaline and epidote.

At Inverugie, sandstones of a somewhat browner cast but otherwise similar in almost every respect to the beds described above, crop out between the Cherty Rock and the pebbly sandstones below. In thin sections (46841) [15076859] and (46845) [14666841] these maintain the feldspar content (about 20 per cent) seen in specimen (46840) and include small amounts of zircon, green and brown tourmaline, garnet and green spinel. Some of the sandstone has two distinct grain sizes, a smaller feldspar content and a calcite cement (46846) [14696841]. A grain of hornfels is to be seen in this latter section.

Farther east in the St. Peter's Well bore at Duffus [17206874], the same sandstone band, some 25 ft thick, has been recorded (46867–8): here a little biotite and muscovite occur with about 20 per cent feldspar. The borehole offers a complete section from the Cherty Rock through the fine-grained sandstone into the pebbly sandstone. A specimen (46869) from a depth of 54 ft near the junction with pebbly sandstone, is similar to the foregoing, but finer-grained (0·1–0·2 mm), and with a cement of granular calcite. Blebs and flecks of magnetite and leucoxene are present, and zircon is the commonest heavy mineral followed by rutile, tourmaline and epidote.

The pebbly sandstone, of which some 60 ft are penetrated in the well, varies from pale yellow-brown towards greyish-red (10 R 4/2). Among the pebbles, which may exceed 2 cm in diameter, are psammitic granulite, quartzite, crushed granite or gneiss, chert, rhyolite, hornfels, ferruginous feldspathic sandstone and fresh but crushed microcline (46870, 46872–4). Some finer-grained bands (0·1–0·3 mm) are intercalated (46871), but in much of the succession the clastic grains of quartz may exceed 2 mm across. Quartz is always the dominant clastic mineral, with feldspar (fresh microcline and cloudy untwinned potash feldspar) varying between 10 and 30 per cent of the allogenic constituents. The chief cementing material is secondary quartz, with feldspar overgrowths on the feldspar, and it may be remarked that growth and corrosion have modified many of the smaller feldspar grains to cleavage fragments (46874). Patchy interstitial calcite occurs in the cement of specimens (46872–3). The sparse accessory minerals in the five sections include zircon, apatite, sphene and micas.

Though heavy minerals are usually uncommon, a specimen from a depth of 89 ft in the borehole (46875) is an exception. This is a fine-grained, greyish-orange sandstone (10 YR 7/4) with heavy minerals concentrated in the more ferruginous silty bands. About 50 grains of apatite and 40 of zircon were noted in the thin section together with a little tourmaline and epidote.

The water-laid beds exposed below the main Lossiemouth quarries vary from coarse- to fine-grained, yellow, grey and red-brown sandstones with beds of siltstone. Two of the specimens collected (46852–3) [23547062] are of fine-grained sandstone nearing silt grade, with scattered larger quartz grains. The angularity of the clastic minerals and the relatively poor sorting is in sharp contrast to the wind-blown Triassic above, but their composition is much the same with quartz predominating over about

10 per cent microcline and clouded potash feldspar, a little chert, muscovite and biotite. A little magnetite (0·05 mm) is concentrated on the bedding planes. Calcite, which forms large plates, has partly replaced the clastic grains and makes up much of the cement, the remainder being secondary quartz. The heavy minerals, which are more frequent than in the wind-blown sandstones, are dominated by zircon, with a little tourmaline, rutile, apatite and hornblende.

Sandstones of Spynie, Lossiemouth and Findrassie

The Sandstones of Spynie, Lossiemouth and Findrassie, of Upper Triassic age, crop out at the eastern ends of the two east-north-easterly trending bands of Permo-Triassic Strata.

Details

Lossiemouth. The Upper Triassic sandstones are well seen in the old quarries on the south side of the hill at Lossiemouth. In the quarry [232704] west of the School Brae, about 30 ft of hard, white, fine-grained, laminated and even-grained sandstone are exposed, with about 5 ft of till on top. The rock is closely-jointed with a dominant west-north-west-trending set and a subordinate north-north-east set, both sets dipping nearly vertically. The former is composite (i.e. two joint directions with an angle of about 20 degrees between them) and the joints often carry fillings of barytes and brown fluorspar, such fillings being over an inch across in places.

East of the School Brae the rock has been quarried for a distance of 400 yd SW. of the railway station. The quarry floor, which approximates to the contact of the siliceous sandstone with the softer material below, is higher than the floor of the quarry west of the School Brae, probably because of a small (unexposed) fault near the line of the School Brae (Westoll *in* Watson and others 1948). At a point 400 yd WSW. of the station about 25 ft of fine-grained, pink and white massive siliceous sandstone follow on above the softer sandstone (described under Burghead Beds, p. 66). In the middle of the quarry about 40 ft of hard to friable, yellow and grey sandstone is seen, and weathering has etched out large-scale cross-bedding which occurs in units 15 to 20 ft thick and over 100 ft long. On the shore east of Lossiemouth Station very hard, grey, cross-bedded 'millet-seed' sandstone with a carbonate cement crops out at and below high-tide mark, and hard pink and grey sandstones are visible at points northwards to the harbour where they pass upwards into chert and cherty limestone.

On the north and west side of Lossiemouth the best exposures of the Lossiemouth sandstones is in the cliff of the post-Glacial beach, overlooking the golf course. Here there are numerous outcrops of very hard, light grey to pink sandstone, mainly siliceous, but with a calcareous cement in places, particularly near the transition towards the Cherty Rock. At a point 150 yd west of the church [227707] a thickness of some 20 ft of pink siliceous sandstone is seen showing large scale cross-bedding and joint fillings of quartz, calcite, barytes, galena and pyrite. About 150 yd to the NE. the contact of the Triassic sandstone with the chert is beautifully exposed [22677072], the sandstone a few feet away from the contact being medium- to coarse-grained with 'millet-seed' grains. As the contact is approached the rock becomes fine-grained with numerous larger rounded quartz grains (2 mm), and the cement highly siliceous or calcareous. This 'sago-pudding' sandstone (p. 71) passes laterally and upwards into the Cherty Rock, the actual contact being sharply defined, but irregular in detail. The Cherty Rock itself varies from rhythmically-banded chert to a honeycomb of chert and limestone, and to a rock with chert fragments in a calcareous matrix. As in other exposures there are numerous cavities lined with quartz crystals. The close blocky jointing in the sandstone does not continue into the chert.

Eastwards, hard to soft and friable, grey sandstone rises from below the Cherty Rock at various points along the faulted contact with the Old Red Sandstone north-east of Maggie's Craig [227710]. At a locality [22957121] near Maggie's Craig is the Jurassic sandstone reported by earlier observers. Much of the shore section, however, between Stotfield and the harbour at Lossiemouth is formed of Cherty Rock which consists of white limestone and white to dark brown chert. Irregular bodies and 'rafts' of silicified sandstone may be seen at some points, and drusy cavities filled with quartz, calcite and hematite are common, particularly in the more siliceous parts of the rock. The limestone often contains numerous tiny pellucid quartz grains. At Maggie's Craig and on the north side of Lossiemouth harbour the rock passes down into fine-grained, siliceous sandstone, but at the west end of the harbour the calcareous and siliceous 'sago-pudding' variety of sandstone is seen at the contact. Veinlets and irregular disseminations of quartz, calcite, pyrite and galena are common especially near the old lead mine [22957105], and north of Lossiemouth harbour joints carrying barytes pass from sandstone into the chert. Casts of fluorspar crystals can be seen near the old mine.

Spynie. Though the area of Middle to Upper Triassic sandstone on the Hill of Spynie west of Spynie Farm is small, it has been extensively quarried. During the present revision five quarries were to be seen. At the most westerly, in a plantation at a bend in the Elgin–Lossiemouth road, about 16 ft of fresh to weathered fine- to coarse-grained grey sandstone is overlain by a few feet of broken rock. The rock is less closely-jointed than that at Lossiemouth but similar fluorspar fillings occur. The upper half of the face is a unit of cross-bedding some eight feet thick inclined to the north-east at about 30 degrees. This quarry is reputed to have yielded *Hyperodapedon* (Gordon *in* Huxley 1877). Over a boundary fence some 150 yd due E. is a small but deep quarry [22066557] exposing about 40 ft of grey sandstone. This is evidently the remnant of a much larger quarry in which specimens of *Leptopleuron* ('*Telerpeton*') were found.

East and north of the last-mentioned locality is an extensive quarry with two main faces showing 20 to 25 ft of massive sandstone with a soft, flaggy and largely uncemented band about 10 to 15 ft from the top. At the north end, near the recently erected crushing plant, these are overlain by a few feet of concretionary sandstone with a ferruginous and calcareous cement, while at the crushing plant itself the joints trending north-west are filled by fluorspar, calcite and galena. These excavations are now partly covered up by quarry waste.

Farther east another composite excavation is seen [22256565] exposing more than 55 ft of sandstone. The upper part of the quarry, recently worked for roadstone, is in massive, hard, fine-grained, grey sandstone, sometimes highly siliceous and more rarely calcareous, with occasional planes of bedding dipping to the north at a low angle. A pit in the quarry floor shows 35 ft of somewhat softer weathered, greyish-yellow, calcareous sandstone. There is little or no trace of cross-bedding in any part of the succession, but the joints are well-marked and coated with sparse fluorspar, galena, and blende. In the upper part of the quarry some joints and fractures are open and infilled with sand and clay from above, a phenomenon no doubt connected with frost-heaving during the Pleistocene. Above the quarry face the transition from sandstone to the Cherty Rock can be seen. The top of the sandstone is hard and siliceous with cavities infilled by soft ferruginous and manganiferous material, and the Cherty Rock itself contains vugs lined by quartz and calcite. About 2 ft of massive, dark grey and brown chert is seen in the nearby plantation [22356560]. Including the section obtained from the Geological Survey borehole in this quarry (Appendix I, p. 131), the succession at this locality is as follows:

	Ft	in
Cherty Rock	5	0+
Sandstone, hard and siliceous at top, softer below	76	6
Yellowish calcareous siltstones with thin beds of gritty sandstone	26	10
Siltstone and sandstone with galls of green clay. Some reddish-brown coloration	4	0+

These last beds are presumed to be of Upper Old Red Sandstone age, and the total thickness of the Triassic rocks appears to be a little over 100 ft.

The fifth quarry [22326549] on the Hill of Spynie is about 730 yd due W. of Spynie farm and exposes 25 ft of much-weathered massive sandstone, harder and more calcareous towards the top. As in the other openings the rock is sometimes overlain by a thin covering of till.

Sandstone of Triassic age probably underlies some of the ground between the Hill of Spynie and the River Lossie, and is overlain by chert and sandy limestone at the old Palace of Spynie [231659] and near Scarffbanks [239662]. At the latter the typical hard, light grey siliceous sandstone can be seen in an overgrown quarry 200 yd NNW. of the farm. Soft, medium-grained, yellow-brown sandstone is visible at two points, one 400 yd NNE. of Scarffbanks, and the other in the remains of a small quarry [23576530] 700 yd ESE. of Spynie Farm. At the Palace of Spynie exposures at the base of the bank of the former Loch of Spynie show some 8 ft of dark chert overlying pink and white limestone and calcareous sandstone. Cavities in the chert are lined with quartz and calcite, and spherulitic calcite occurs in the sandstone. Galena is sparsely distributed in the chert. Another small exposure [23726630] of the chert can be seen on the shore of Loch Spynie north-west of Scarffbanks.

Findrassie. Four hundred yards due south of Lochside [207656] is a shallow overgrown quarry [20726524] exposing patches of sandstone, mainly hard and siliceous, but with cavities formed by weathering. In places the rock resembles the beds transitional to the Cherty Rock on the coast. Similar sandstone is seen in other small openings a few yards to the west and 60 yd to the south, near the faulted contact with the presumed Upper Old Red Sandstone.

Farther west, centred on grid reference 20456510, are three small openings on a north-west to south-east line. The northernmost is almost completely obscured, but the central one still preserves a 20-ft face of massive, fine-grained to medium-grained sandstone, the top part being hard and siliceous and pinkish in colour with scattered larger quartz grains and the bottom yellow to yellow-brown with rusty spots. The southern opening reaches a depth of 16 ft in massive sandstone, the top being much weathered. Barytes occurs on the joints in both openings. On the original Geological Survey six-inch map (Elgin Sheet 7) Linn recorded that *Stagonolepis* was found in the southernmost opening of this group. In a quarry [20756416] in the siliceous pebbly sandstone of the Findrassie area (p. 50) a few feet of weathered yellowish and reddish-brown calcareous siltstone similar to that at the base of the Upper Triassic Sandstone of Spynie occur above the pebbly sandstone. This exposure is on the south side of the fault which in general forms the boundary between the Upper Old Red Sandstone and the Triassic, suggesting that the fault in question has a throw of only a few tens of feet.

Inverugie. Apart from a small outcrop of chert on Gallow Hill [147684] exposures of Cherty Rock are confined to the old limestone quarries north and west of Inverugie House [152686]. At a small quarry 350 yd N. 80° W. of the house, 11 ft of chert and siliceous sandstone are seen with veinlets of chert and calcite; and 230 yd N. 70° W. of the house, 8 ft of massive to well-bedded, pink limestone and chert with scattered sand grains and cavities lined with quartz and calcite still remain in another largely obscured quarry. This latter locality also yields a little disseminated galena.

PETROGRAPHY

LAMINATED AND EVEN-GRAINED SANDSTONES

In the Spynie and Findrassie quarries, and from Lossiemouth harbour to Stotfield, the sandstones are generally even-grained. On the south side of the hill of Branderburgh, however, finely-laminated sandstones, as well as the even-grained variety, are exposed in the old quarries. Below the main Lossiemouth quarries there are a few feet of colour-banded, calcareous sandstone and siltstone (described on p. 65).

Specimens from the Spynie quarries (46832) [22296562] and from Stotfield (40854) [22977097] are of compact, even-grained, fairly hard sandstone with a grain size between 0·2 and 0·5 mm. The grains are mainly well-rounded, with a high sphericity, but the feldspar (about 10 per cent of fresh perthitic microcline and cloudy orthoclase) tends to be tabular. Apart from the quartz and feldspar there are a few grains of brownish chert and quartzite. Cementation in much of the sandstone is by overgrowths of secondary quartz and feldspar which may completely fill the interstices between the grains. In one section (46832) there are a few patches cemented by calcite and fluorspar. Another specimen (46848) [22667068], collected from the old sea-cliff at Stotfield, is similar to the foregoing, but the quartz is slightly coarser-grained (0·5–1·0 mm) and a grain or two of hornfels can be seen. Like specimen 46832 it contains a small proportion of fluorspar which tends to replace the secondary quartz but leaves the overgrowths on the feldspar relatively untouched. Heavy minerals are rare in thin section, only zircon and garnet being observed. Mackie (1925) found that garnet was a characteristic beavy mineral of the Triassic, and noted its virtual absence in the Hopeman and Quarry Wood sandstones.

Examples of the laminated sandstones (51075, 51077–8) from the westernmost quarry [232704] at Lossiemouth show well-defined laminae with a grain-size between 0·1 and 1·0 mm. The grey or pale yellow colour of the rock is modified in places by spots of dark brown iron ore which coalesce parallel to the laminae. The composition of the clastic grains is the same as in the even-grained sandstones. Most of the cement is secondary quartz, but a little calcite was noted in one section (51075) and spots of fluorspar (1 mm) in the other two. Zircon, tourmaline, ? amphibole, and monazite occur in the very sparse heavy mineral assemblage.

THE CHERTY ROCK

The Cherty Rock is a complex sediment comprising chert, sandy limestone, calcareous sandstone, and silicified sandstone. Three specimens from the borehole at St. Peter's Well, Duffus (46864–6) [17206874], illustrate the variety of textures and lithologies.

One specimen (46866) is a medium grey (N/5) to light grey sandstone, highly calcareous, with quartz-filled vugs. Under the microscope the following types of material were distinguished:

(1) Sedimentary quartzite in which clastic quartz grains (with a diameter of 0·1–0·3 mm) and some larger clastic grains (up to 1 mm in cross-section) with about 5 per cent of fresh microcline are set in a cement of secondary quartz. The feldspar is commonly euhedral, retaining shadowy outlines of the original clastic grains

(2) Rhythmically banded chalcedony containing feldspar rhombs and corroded grains of clastic quartz. The chalcedony replaces the sedimentary quartzite (1) and evidently post-dates the outgrowths on the feldspar

(3) Quartz-mosaic rock in which individual quartz crystals enclose granular calcite outlining the original sand-grains. The tabular feldspars, which occur in small quantities, are only slightly corroded, but show no traces of outgrowths. This rock grades without discontinuity into (2)

(4) Rock consisting of fine- to coarse-grained calcite in which there are corroded quartz grains and a few small areas of chalcedony. This material grades into (3), but has a sharp and irregular contact with (1)

In the second section (46864) the clastic quartz grains of quartzite of type (1) above are outlined by numerous tiny needles and rhombs of authigenic alkali feldspar. The third specimen (46865) is composed principally of type (4), but also contains the following:

(a) Veinlets and irregular areas of coarse-grained calcite with blebs of rhythmically banded chalcedony
(b) Veinlets of drusy quartz cutting (a) above
(c) A veinlet of coarse-grained quartz with some calcite, galena, and fragments of the calcite rock (type 4 above)

Two specimens of Cherty Rock, one from Inverugie (46844) [15056863], and the other from Lossiemouth (46858) [23517132], are similar respectively to type (4), and to types (3) and (4) above. In both cases the calcite rock of type (4) is partly replaced by banded chalcedony probably equivalent to that in (a) above. In a further specimen from the Lossiemouth locality (49231) [23517132], fragments of calcite rock similar to type (4), but with scattered euhedral quartz grains are set in an intimate mixture of fine-grained calcite, quartz and chalcedony. Some parts of the slice are composed of concretionary calcite partly replaced by rhythmically banded chalcedony. The fragmented appearance is accentuated by microstylolites outlined by chert and brown organic matter, and the whole is sharply cut across by a veinlet of calcite, quartz and galena, representing a period of mineralization exemplified by (c) above.

'SAGO-PUDDING' SANDSTONE

At Stotfield, and at various points along the coast to Lossiemouth, a small thickness of siliceous or calcareous sandstone characterized by two grain sizes (giving the appearance of sago-pudding) occurs in places between the Cherty Rock and the even-grained sandstones below. Specimens of the 'sago-pudding' sandstone (46849–51) [22687073] consist of about 20 per cent of larger grains (1–2 mm diameter), comprising quartz, microcline, metamorphic quartzite, vein quartz and chert, set in a matrix of dominantly sub-rounded to sub-angular grains (0·1–0·3 mm diameter) of the same constituents together with a little muscovite. At a distance of 10 ft from the Cherty Rock (46849) the cement is of calcite, whereas within 2 ft of the Cherty Rock (46850–1) it is of chalcedony. A similar rock from Lossiemouth Harbour (46857) [23517128] is of sandstone in which a cement of chalcedony and scattered euhedral calcite rhombs is replaced by plates of calcite (up to 1 mm). The smaller sand-grains are corroded where in contact with the replacing calcite. The 'sago-pudding' sandstones carry a larger and more varied suite of heavy minerals than the sandstones below them, and contain, in particular, zircon and subordinate scattered grains of biotite, garnet, apatite, tourmaline, rutile and topaz. The abundant heavy minerals, together with the angular shape of many of the sand grains suggest deposition by water. The cementing substances have replaced the clastic grains to a much smaller extent than in the Cherty Rock above.

SUMMARY

In the laminated and even-grained sandstones, the shape of the grains and the sparse suite of heavy minerals are in keeping with aeolian deposition. The 'sago-pudding' sandstone was probably deposited by water. The complex lithologies of the Cherty Rock are the result of the partial or entire replacement of a silica-cemented sandstone, initially by calcite, and subsequently by chalcedony. The last event recorded in specimens of the Cherty Rock is the quartz-calcite-galena mineralization.

CONDITIONS OF DEPOSITION

From what has been said in the foregoing pages there is little doubt that the bulk of the Cutties Hillock and Hopeman sandstones is wind-deposited, but there is evidence also of a certain amount of water action. Consideration of the azimuths and dips of cross-bedding in the Hopeman sandstones suggests that the dominant wind was from a north-easterly point with a subsidiary maximum from just east of south. This is in broad agreement with Sbotton (1956, fig. 2) and Opdyke (*in* Nairn 1961, p. 53 and fig. 3). Sufficient readings have not been obtained from the Cutties Hillock sandstone at Quarry Wood and at Carden Hill to be significant, but those available also suggest a derivation from a north-easterly direction.

The origin of the penecontemporaneous disturbed bedding in the Hopeman sandstone has been discussed in detail elsewhere (Peacock 1966). It is suggested that the disturbance occurred while the sand was partly dry and partly damp, the water acting as a cementing substance. When movement took place the wet sand retained sufficient coherence to form brittle-style folds at some localities, but at others the beds yielded by fracture. The dry sand, being in a loosely-packed condition (Bagnold 1941), behaved like a quicksand. Thus once-continuous laminae of damp sand, broken during movement, were separated by the flow of the dry sand to give rise to tbe fragments of bedded rock now seen in structureless sandstone, the latter derived from incoherent dry sand. The cause of the movements is in some doubt, but may possibly be connected with undercutting of unstable dune faces by the floodwaters associated with local cloudbursts.

Unlike the remainder of the Permo-Triassic rocks of the Elgin district, the Burghead Beds are dominantly water-laid, though the occurrence of horizons with faceted pebbles is suggestive of exposure to wind. The strong but relatively small-scale cross-bedding, the silty laminae, sometimes affected by desiccation cracks, and the occasional occurrences of pellet conglomerates strongly suggest fluviatile, probably floodplain conditions in an arid or semi-arid environment. Temporary lakes would allow the accumulation of rare thicker beds of silt and clay. However, the apparent absence of a fish fauna such as that which flourished during Old Red Sandstone times, and indeed the lack of fossils of any description, including plants, suggests that conditions were relatively unfavourable to life. The dearth of organic remains could, of course, also be attributed to the conditions being inimical for their preservation. Whether or not the thin water-laid beds below the Lossiemouth quarries are representatives of the Burghead Beds, the thickness of the pebbly sandstones evidently diminishes rapidly from west to east. Measurements of cross-bedding at Burghead suggest that part at least of the sediment was transported from the west.

Some of the characteristics of tbe Sandstones of Spynie, Findrassie and Lossiemouth such as the large-scale cross-bedding, the apparent absence of pebbles, the well-rounded sand grains of high sphericity, and the paucity of micas and heavy minerals are suggestive of aeolian deposition, and indeed Shotton (1956, p. 451) has remarked that tbe Lossiemouth sandstone is the only undoubted aeolian sandstone he has seen in the Trias of the British Isles. The few readings of dip and direction of the cross-bedding indicate derivation of the sandstones from a southerly point. This presumed aeolian sandstone is underlain by a few feet of water-laid sandstone and is overlain by the Cherty Rock, a chemical limestone and chert formed by replacement of sandstone.

An assessment of the extent of the Upper Triassic in the Elgin area is hindered by the extensive drift cover, but it is perhaps significant that at Inverugie cherty limestone correlated with the Cherty Rock rests directly on Burghead Beds. It would seem, therefore, that the aeolian sandstone may be restricted to a small area.

It has been pointed out by Walker (1961, p. 195) that the reptilian fauna of the Elgin Triassic may be of two types, the one adapted to grubbing for roots or invertebrates, and the other to life in a sandy terrain. If, as is suggested above, the area of aeolian sand is limited, the anomaly of the preservation of reptiles adapted to different environments within the same bed is more apparent than real. The evidence suggests an environment similar to that postulated for the uppermost part of the Burghead Beds, i.e. floodplain conditions accompanied by a semi-arid or arid climate which allowed the accumulation of areas of sand-dunes away from the active river channels.

The Cherty Rock has been compared by Watson and Hickling (1914, p. 3) to the superficial chalcedony of dry sandy regions, and it is noteworthy, as has already been pointed out, that a cornstone-like deposit with chert occurs at a similar horizon in the Dunrobin area of Sutherland (Judd 1873). There is, in the Cherty Rock, some resemblance to concretionary cornstone (Burgess 1961) and caliche (Brown 1956), but the large amount of chert is foreign to these rock types. Some of the quartzitic sandstones resemble silcrete (Frankel and Kent 1937; Wayland 1953) but the difficulty still remains of accounting for the large quantity of chert, even allowing for a long continuation of the particular environmental conditions under which surface quartzites form.[1] The additional material may have been derived from contemporaneous hydrothermal solutions, over and above that transferred by and precipitated from local groundwater, though there is no direct evidence of this. The cherts and limestones have evidently acted as host rocks for later mineralization, which probably took place under an impermeable cover of Jurassic shales.

The Millstone (Cutties Hillock) Quarry in the Latter Half of the Nineteenth Century

In 1864, according to Harkness, the quarry then showed 'white sandstone with conglomerate, the lower beds being red, and the upper strata, as seen on the north side of the quarry, white and cherty'. The location given by Harkness, about a third-of-a-mile to the west of Laverockloch Quarry, is doubtful, since the true distance is nearly twice as great. However, since at that time there was no intervening quarry, Harkness's account can refer only to the Millstone Quarry.

By 1878, the date of the primary survey, the quarry (which comprised four separate openings) was 'very much covered up', but Linn recorded that it still gave a section showing 20 to 25 ft of hard, jointed, pinkish sandstone resting on a coarse grit with numerous quartz and other pebbles (MS. 1886). Large-scale cross-bedding was visible, and one of the bedding planes showed an 8-ft long row of well-preserved footprints.

About the beginning of 1882, the quarry was reopened (Judd 1886, p. 399). In 1884, Judd saw a cast of a dinosaur-like reptile, procured from the quarry, in the Elgin Museum (Judd 1886, p. 395) and recorded that 'From the same quarry a skeleton apparently belonging to another lizard, distinct alike from *Telerpeton* and *Hyperodapedon*, with portions of the skeleton of the last-

[1] The conditions of formation of such rocks are obscure since 'recent' silcretes and ferricretes often appear to be related to climatic conditions of past ages (e.g. Cooke 1958, Langford-Smith and Dury 1965) and dependent in any case on the local soil environment (Mason and others 1959).

mentioned genus[1] were also obtained'. In the autumn of 1885, on returning to Elgin immediately before the Britisb Association meeting in Aberdeen, Judd was sbown another reptilian specimen which he thought was akin to *Dicynodont*, an identification confirmed by Traquair from a photograph a few days later (Traquair 1886). This specimen was later described by Newton (1893) as *Gordonia traquairi*. By 1893 Newton had also received other material from the Geological Survey and the Elgin Museum including other species of *Gordonia* and tbe reptilian skull *Elginia mirabilis* (1893, p. 473).

Between 1882 and 1884 (probably near the earlier date) a trial pit was sunk below the level of the pebbly rock described by Linn. It was driven to a depth of 13 ft and possibly as much as 22 ft below the conglomeratic bed (Judd 1886, Phillips 1886), and at the bottom a specimen of *Holoptychius nobilissimus* Agassiz was obtained. During September 1885 the trial pit, whicb had long been filled in, was partly re-excavated with the aid of a Royal Society grant, and from this, together with information obtained from the quarrymen and from quarry debris, Judd pieced together tbe following section (condensed from Judd 1886, pp. 400–2):

	Ft
Coarse sandstone, white to pale yellow, often feldspathic and gritty, becoming pebbly downwards. Five reptiles recovered from one horizon, and one from the course of stone below	20
grades into	
Conglomerate. Pebbles of white and purple quartz up to fist size, about	4
sharp contact	
Finely-laminated pink and red sandstone with much false-bedding Yielded at base *Holoptychius nobilissimus*	13

The Royal Society excavation exposed the contact between the conglomerate and the underlying beds over a horizontal distance of ten feet, and was examined by Judd, Bonney, and Phillips. Phillips, the then curator of the Elgin Museum, confirmed tbat the sandstone below the conglomerate was finely laminated but did not tbink that there was a great litbological distinction between the upper and lower beds and that the degree of unconformity was of no great significance (Phillips 1886). In a footnote (p. 1023) be observed that at a later date the workmen excavating on the north side of the quarry encountered no conglomerate while going into sandstone which he regarded as identical with that containing the *Holoptychius*.

After bis visit to the Millstone Quarry in 1885, Linn, the Survey Officer responsible for the primary mapping, noted that since 1882 working had been continued on a ratber extensive scale. Writing in 1886 or 1887 he recorded:

'A deptb of about 50 ft was reached. The lowest part is a softish yellow sandstone, sometimes gritty and containing pebbles of white quartz. In this yellow sandstone a remarkably fine specimen of *Holoptychius* was found about five years ago. It is now in the Elgin Museum. The sandstone as it rises becomes in some places more pebbly, greyisb in colour and coarse-grained. In one part seen, the white quartz pebbles are somewhat thick, but gradually get fewer on either side. The stone continues nearly the same up to tbe hard pinkish jointed sandstone with planes of bedding running in all directions and at various angles like that on tbe sbore and in the cliffs and quarries between Burghead and

[1] Not confirmed by later work.

Lossiemouth. This is the only place at present known where a section can be seen in which Holoptychian remains are found in the lower part and reptilian remains 20 or 25 ft above. It is very remarkable, however, that in examining the section no trace of any break in the continuity can be seen'.

The conflict of opinion and fact between the Survey account and that of Judd was noticed by Newton (1893, p. 434) and it is unfortunate that no attempt seems to have been made at the time to resolve the factual difference. Judd and Bonney evidently saw only the uppermost bed below the conglomerate in the Royal Society excavation, and it is unlikely that Linn saw it at all, though it seems he may have been in the quarry at a slightly later date when the conglomeratic bed was thinning out as reported by Phillips. It is of interest in this connexion that the specimen of *Holoptychius* in the Elgin Museum said to come from Cuttie's Hillock Quarry is preserved in a matrix of fine-grained, grey, micaceous sandstone, not pink or red as would be expected from Judd's account, or yellow as stated by Linn. J.D.P.

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Chapter VII

JURASSIC

General Account

Sediments of Liassic age considered to be *in situ* are preserved beneath thick superficial deposits to the south-west of Lossiemouth and they are also inferred to be present at two localities in the Spynie area. A small exposure of Jurassic sandstone which occurs on the shore at Stotfield, Lossiemouth, was referred to the Inferior Oolite by Judd (1873, pp. 163–4) but this age was questioned by Lee (*in* Read and others 1925, p. 79). Its relationship to the surrounding strata is not clear (see below). Fossils indicating a wide range of Mesozoic ages have been collected from glacial erratics in the Elgin District (Judd 1873) including many from the Jurassic. A notably large erratic block formerly exposed at Linksfield, Elgin was thought by Duff (1842, p. 16) to be Lower Purbeck or Wealden as were others in the neighbourhood of Elgin. Moore (1860), Jones (1863) and Anderson (1964), however, referred this occurrence to the Rhaetic. Descriptions of the Linksfield exposure suggest a correlation with an alternating marl-cementstone sequence of inferred Lower Liassic age encountered in a Geological Survey borehole near Lossiemouth sunk in 1965. This borehole, the log of which is summarized in Appendix I, is the source of most of the data concerning the Jurassic in Morayshire and is specifically described elsewhere (Berridge and Ivimey-Cook 1967). The following description is mainly abstracted from that paper. After passing through 42 ft of superficial deposits (p. 134) the following section of horizontal or gently dipping strata was found:

	Thickness		Depth from top of borehole	
	Ft	in	Ft	in
Sandstone, pale yellowish-grey, for the most part kaolinitic; sparsely occurring plant debris ..	56	3	98	3
Sandstones, siltstones, mudstones and shales, generally grey, often bioturbated or otherwise disturbed; much plant debris near the top ..	123	3	221	6
Marls and cementstones, respectively greenish-grey and olive-grey; alternating sequence	30	10	252	4
Marl, greenish-grey with some subordinate cementstone nodules	17	8+	270	0

Boundaries between the lithological groups defined above are transitional generally through a graduated sequence of intermediate phases, suggesting that sedimentation was essentially continuous. Between 193 ft 11 in and 194 ft 4 in, however, there occurs a distinctive horizon predominantly composed of mudstone fragments and rounded grains and ooliths of limonite; sand grains, pyrite and organic phosphate were also identified. This bed is believed to indicate a non-sequence but available evidence suggests that the hiatus was small and unlikely to have broken the zonal continuity. Thus, apart from an anomalous 8-ft greenish mudstone immediately underlying the limonitic horizon, the lithologies and faunas from above and below the non-sequence are similar although fossils of zonal value have unfortunately only been obtained from above it.

Small-scale rhythmic sedimentation is well displayed in at least two parts of the section. The first of these is the cementstone group, in which each marl band has a sharp planar base but is transitional upwards into the associated limestone, and the second is a 25-ft succession overlying the aforementioned non-sequence. Within the latter succession, it is possible to recognize 5 rhythmic units irregularly increasing upwards from 18 in to 6 ft in individual thickness. Each unit consists of sandy shale or shaly sandstone, laminated or bioturbated, capped by a relatively thin stratum of homogeneous shale, clay or siltstone.

The strata between depths of approximately 120 ft and 251 ft are fossiliferous (see Appendix II, p. 137), but apart from 'worm' tracks in sandstone no animal remains were discovered outside this range.

Upwards from the non-sequence at 193 ft 11 in, an abundant predominantly molluscan marine assemblage was found with *Cardinia attenuata* (Stutchbury), *Grammatodon insons* Melville, *Pseudolimea* and *Pseudopecten* being especially prominent. In addition, besides small numbers of gastropods and brachiopods, the sequence yielded a few zonally significant ammonites. Those collected from between 153 ft 5 in and 155 ft 10 in are identified as *Paltechioceras aureolum* (Simpson), indicating the *Paltechioceras aplanatum* Subzone of the *Echioceras raricostatum* Zone. Poorly preserved specimens from between 172 ft 8 in and 172 ft 11 in are referred to *Echioceras sp.* cf. *typicum* (Trueman and Williams), indicative of the *E. raricostatum* Subzone of the same zone. The ammonite-bearing strata are thus Upper Sinemurian in age.

The limonitic horizon has a marine fauna including *Liostrea irregularis* (Münster) but the underlying 8 ft of greenish mudstone only contain a few fragments of *?Euestheria*. Between 203 ft and 213 ft there is a lamellibranch fauna similar to that from above the non-sequence but less diverse in character. It also includes well preserved specimens of *Lingula sacculus* Chapuis and Dewalque.

Marine lamellibranchs are absent from the fauna collected from between 213 ft and 251 ft, which is dominated by *Euestheria minuta* (Alberti *in* Zieten) and darwinulid ostracods. Some fish fragments are also present including teeth of the selachian *Hybodus* cf. *lawsoni* Duff.

There is a remote possibility that the Liassic rocks penetrated by the Lossiemouth borehole are part of an erratic block. This is considered to be unlikely in view of the thickness of strata involved and of its appropriate occurrence on the downthrow side of the projected line of the major east-west fault exposed at Stotfield (*see* p. 6).

It is considered that the entire succession of solid rocks in the Lossiemouth Borehole is probably Lower Liassic in age, although some doubt remains concerning the importance of the included non-sequence. It cannot be conclusively proved that the borehole does not penetrate to the Triassic but the lowest rocks are lithologically dissimilar both to the Upper Triassic rocks of Lossiemouth (*see* p. 67) and to the Trias (including the supposed Rhaetic) of Golspie (Lee *in* Read and Phemister 1925).

The environment of deposition of the Lossiemouth Liassic succession apparently varied between marine and non-marine. Initially lagoonal conditions seem to have prevailed, becoming progressively more saline during the deposition of the strata between 221 ft 6 in and 193 ft 11 in. A subsequent recession of the open sea is implied by the lack of a marine fauna above 120 ft, by the abundance of plant material between 107 ft 6 in and 98 ft 3 in and by the subsequent incoming of large quantities of kaolinite. The general palaeogeographic picture accords very well with the littoral status proposed for this area by earlier workers (Arkell 1933, p. 595; Hudson 1964, pp. 521–24).

The only other known occurrence of Lower Liassic rocks in north-east Scotland is across the Moray Firth on the shore at Dunrobin Castle, Sutherlandshire (Judd 1873, Lee *in* Read and others 1925). A recent re-assessment of the ammonites from this locality by Prof. D. T. Donovan (Berridge and Ivimey-Cook 1967) indicates that the datable strata belong to the *Echioceras raricostatum* (*P. aplanatum* Subzone) Zone and the *Uptonia jamesoni* Zone. Although no fossils of the *U. jamesoni* Zone have been recoveied from the Lossiemouth Borehole the strata above 153 ft may include beds of this age. Lithologically the ammonite-bearing succession at Dunrobin Castle differs most notably from its Lossiemouth counterpart in containing several highly calcareous beds. The underlying strata at this locality, though poorly exposed, have been estimated (Judd 1873, Lee *in* Read and Phemister 1925) to include a considerable thickness of argillaceous strata with a few thin coal seams. It is concluded that lithological correlations across the Moray Firth are not yet possible.

With respect to structure the occurrence of Lower Liassic rocks near Lossiemouth supports the hypothesis that the Moray Firth was a Mesozoic basin of deposition (Arkell 1933) and, by inference, now conceals deposits of that age. The original interpretation was based on the evidence of Mesozoic outcrops on the Sutherland coast and erratics on the southern side of the Firth. The presence of a negative gravity anomaly (Colette 1960) has also been interpreted as evidence in support of this theory (Hallam *in* Craig 1965, p. 414). However, the possibility that the sedimentary basin in the Moray Firth includes a considerable thickness of Old Red Sandstone as well as Mesozoic rocks must also beconsidered (p. 145).

The 'Lower Oolite' (Judd 1873, p. 128) between tidemarks at Stotfield, Lossiemouth (referred to earlier) is a reef of soft to very bard grey and greenish grey sandstone about 80 yd in length and 4 ft in thickness with indeterminate casts of shells. The dip of the bed is about 30 degrees to the south. Judd (1873, p. 164) listed a large fauna, mainly of lamellibranchs, from this locality, but the collection on which the names are based cannot now be traced. The contacts are obscured on all sides by sand and bouldery shingle. The primary surveyors concluded that the outcrop was that of a transported block analogous to the Linksfield erratic (p. 77). However, its position [22957121] is within a few yards of the major fault which farther south-west apparently throws the Liassic strata of Lossiemouth Airfield against the Upper Old Red Sandstone, and the possibility cannot therefore be ignored that the Stotfield Jurassic is a fault block, an interpretation in keeping with one of Judd's (1873, p. 128) suggestions.

N.G.B.

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Chapter VIII

MINOR INTRUSIONS

MINOR intrusions of microdiorite and lamprophyre have been mapped in the Dalradian, and a body of andesite or trachyandesite occurs in the Gollachy Burn (p. 40).

Granular Microdiorite. A sill of microdiorite intruding the Cullen Quartzite is exposed on the shore north-east of Cluny Harbour, Buckie. At Bents Point [434664] it is 10 ft in thickness and displaced by three faults trending north-north-west. On the east side of the small bay known as Whale's Wig [436664] microdiorite is again exposed and although the intervening ground is covered by sand and shingle it is probably a faulted extension of the sill at Bents Point. The contact against quartzite is sharp and slightly transgressive. The freshest parts of the sill are grey in colour but much of it is decomposed into fairly soft green or reddish-brown material. It is cut by a few thin quartz-tourmaline veinlets (48137).

Thin sections (48134, 48138) show that the microdiorite is composed of andesine and actinolite with smaller amounts of quartz, biotite, chlorite and hematite. The andesine crystals are subhedral with an average length of about 0·4 mm. They are well twinned and show slight normal zoning. Lying between these large individuals there is a finer-grained intergrowth of quartz and plagioclase which partly replaces the larger feldspars. The actinolite which makes up about 33 per cent of the rock is very pale green in colour and only slightly pleochroic. It occurs as slender prisms in patches which appear to mark the sites of former large prismatic crystals. The outlines of these pseudomorphs are vague and it is therefore impossible to determine whether the original mineral was an amphibole or a pyroxene.

Although the rock has obviously suffered extensive recrystallization it is massive without a trace of foliation. This suggests that it was intruded after the period of intense deformation associated with the F2 folding (p. 20). The recrystallization may have taken place during the period of post-F_2 static metamorphism (p. 30).

Lamprophyre. Two bodies of spessartite cutting the Dalradian are exposed in the Ardmachie Burn due south of Mains of Oxhill [40325948]. They are poorly exposed but approximately vertical discordant contacts are seen in two places at the edge of the westerly body. The easterly body, which is exposed a few yards farther upstream, appears to have the form of a discordant sheet about 10 ft in thickness. The lower contact dips towards the north-west at about 30 degrees. The existence of two separate intrusions is not certain; the sheet may be connected to the dyke-like mass. Much of the lamprophyre is decomposed into soft brown earthy material.

A small isolated exposure of fresh spessartite occurs in the Ardmachie Burn 110 yd upstream from the old railway bridge [41145908].

A minor intrusion in the Findlater Flags is exposed in the east bank of the Allobane Burn, 450 yd S. 37° W. of Berrybands [41955962]. The intrusion has the form of branching dykes and sheets witb a maximum observed thickness of 3 ft. A positive identification of the rock is impossible because it is completely decomposed into soft green earthy material, but it is most probably weathered spessartite.

The spessartites from the Ardmachie Burn are medium-grained, dark-coloured rocks witb very abundant prisms of amphibole set in a pink and greenish groundmass. In slice (47062–3) the most conspicuous mineral is an amphibole which occurs as euhedral prisms with a rather stumpy habit. It has the following pleochroism: X pale yellowish-green, Y greenish-brown, Z brownish-green. Each crystal has a narrow border showing slightly greater absorption and a few have minute outgrowths of green amphibole. Pale-green pyroxene is also present. It forms subbedral grains whicb are smaller than the amphibole crystals and shows extensive alteration to chlorite, carbonate and epidote. Both acid plagioclase and potasb feldspar are present but owing to fairly advanced alteration they are difficult to distinguish without artificial staining for potash. Broad latbs of plagioclase showing coarse lamellar twinning enclose abundant granules of epidote and much indeterminate dust. Tbey appear to be albite or albite-oligoclase but the presence of secondary epidote suggests that they were originally more calcic. Many are surrounded by a broad rim of potash feldspar which is partly decomposed into brownish turbid material. Potash feldspar probably makes up as much as 50 per cent of the total feldspar. Small amounts of quartz form anhedral crystals lying between the feldspar laths. A little interstitial carbonate is present. Epidote, in addition to occurring as an alteration product of feldspar, also forms radiating tufts of crystals filling spaces between the feldspars. The accessories are ore (probably ilmenite), and apatite which forms long colourless needles in the feldspar.

Petrographically similar lamprophyres have been described from Aikenway, near Rothes (Flett *in* Hinxman and Wilson 1902, p. 42) and from the Shevock (Read 1923, p. 164). F.M.

Gollachy Burn Andesite. The field relations of the andesite in the Gollachy Burn are discussed earlier (p. 40). In thin section, the andesite, or trachyandesite (813, 48148, 49738, 50845) contains numerous microphenocrysts and some small laths of labradorite, pseudomorphs in hematite, chlorite and carbonate after euhedral hornblende and pyroxene, some rather resorbed plates of biotite and small plates and grains of iron-ore in a plentiful fine-grained groundmass. The groundmass is composed of abundant tiny microlites of plagioclase, about andesine in composition, with interstitial spongy plates of alkali feldspar. Minute granules of translucent, red iron oxide and iron-ore speckle the matrix. Quartz, locally with carbonate, occurs in irregular amygdaloidal patches, locally elongated and connected as veinlets (50845). Near some patches of this type the matrix is locally sieved by quartz. In addition to the small corroded plates of biotite, wbich are partly replaced by hematite, small flakes of later paler fresh biotite occur, particularly associated with the patches of quartz and locally fringing the iron-ore. In one thin section (50845A) the later biotite also occurs as small flakes fringing a resorbed plate of biotite near an area of quartz. Accessory minerals include apatite as small crystals, locally enclosed in the pseudomorphs after hornblende (49738), and rare slender acicular crystals of zircon (813b).

The plagioclase microphenocrysts, which are commonly extensively or, in

TABLE III

ANALYSES OF GOLLAGHY BURN ANDESITE AND LOWER OLD RED SANDSTONES LAVAS

	I	A	B	C	D	E	F	G
SiO_2	62·82	62·81	62·78	62·09	61·49	60·79	60·70	60·12
Al_2O_3	15·02	16·40	15·56	17·30	14·98	17·86	17·98	16·26
Fe_2O_3	4·10	0·55	2·42	3·74	1·51	2·54	0·66	1·67
FeO	0·23	3·27	1·74	0·92	3·84	2·06	2·58	3·76
MgO	0·64	1·64	3·87	2·41	3·22	2·21	2·20	2·52
CaO	4·45	4·46	2·21	3·94	4·56	3·73	7·70	5·47
Na_2O	3·07	3·02	4·34	4·27	3·59	5·00	2·95	4·17
K_2O	5·02	3·60	3·00	2·96	2·80	3·02	3·57	1·19
$H_2O>105°$	1·07	4·04 (both H_2O)	2·11	1·10	1·68	1·39	3·45 (both H_2O)	2·00
$H_2O<105°$	0·78		0·69	0·69	0·23	0·47		1·03
TiO_2	0·66	—	0·63	0·65	0·96	0·69	—	1·44
P_2O_5	0·25	—	0·18	0·39	0·32	0·49	—	0·30
MnO	0·09	0·81	0·08(s)	0·05	0·21	0·11	0·20	0·12
CO_2	1·68	—	—	tr	0·92	tr	—	0·02
Cl	—	—	—	—	0·03	—	—	—
S	*	—	0·03	0·02	—	0·02	—	—
FeS_2	—	—	—	—	0·00	—	—	tr
BaO	*	—	0·1(s)	0·06	0·11	0·06	—	0·04
Allow for minor constituents	0·23	—	0·10	—	—	—	—	—
	100·11¶	100·60	99·84+	100·59†	100·45§	100·44‡	101·36	100·11

* listed with minor constituents; n.d., not detected; tr, trace; (s) spect. det., percentages approximate.

¶ Ba: 500 ppm(s), Co: <10 ppm(s), Cr: 18 ppm(s). Cu: <10 ppm(s). Ga: 13 ppm(s). Li: 35 ppm (s). Ni: 10 ppm(s). Sr: 270 ppm(s). V: 74 ppm(s). Zr: 340 ppm(s). B: 18 ppm. F: 780 ppm. S: 250 ppm.

+ Cr_2O_3: 0·02(s). NiO: 0·01(s). SrO: 0·04(s). V_2O_3: 0·02(s). ZrO_2: 0·01(s).

† ZrO_2: n.d.(s). Cr_2O_3: tr. V_2O_3: n.d.(s). NiO: n.d.(s). SrO: tr(s).

§ (Ni,Co)O: 0·00. Li_2O: 0·00.

‡ ZrO_2: n.d.(s). Cr_2O_3: tr. V_2O_3: n.d.(s). NiO: n.d.(s). SrO: tr(s).

I. Andesite or Trachyandesite. ?Intrusion. Burn of Gollaghy, 330 yd S. 13° E. of Gollaghy Croft. SS 50845. Lab. No. 1994. Anal. J. M. Nunan and G. A. Sergeant, spectrographic work by C. Park. *Sum. Prog. Geol. Surv.* for 1966, in press.

A. Andesite. Lava. Rennieston, Cheviots, Roxburghshire. S 1912. Anal. J. S. Grant Wilson. Geikie 1897, p. 275.

B. Trachytoid andesite. Lava. Alva Glen, west bank, 500 yd upstream from confluence with Glenwinnel Burn. S 42142. Lab. No. 1739. Anal. A. D. Wilson and J. Palframan, spectrographic work by C. O. Harvey and K. L. H. Murray. *Sum. Prog. Geol. Surv.* for 1958, 1959, p. 52.

C. Hornblende-andesite. Lava. Old quarry, 800 yd ESE. of Middle Third, Dunning, Perthshire. S 36913. Lab. No. 1524. Anal. W. F. Waters, spectrographic work by J. A. C. McClelland. Guppy and Sabine, 1956, p. 17.

D. Hornblende-andesite. Lava. Corrie, between Stob Coire nan Lochan and Bidean nam Bian, Glencoe, Argyllshire. S 14576. Lab. No. 359. Anal. E. G. Radley. Bailey and Maufe, 1916; p. 182.

E. Trachyandesite. Lava. Quarry, 1600 yd E. 31° N. of Ledlanet House, Orwell, Kinross-shire. S 36605. Lab. No. 1525. Anal. W. F. Waters, spectrographic work by J. A. McClelland. Guppy and Sabine 1956, p. 16.

F. Andesite. Lava. Whitton Hill, Cheviots, Roxburghshire. S 1909. Anal. J. S. Grant Wilson. Geikie, 1897, p. 275.

G. Augite-andesite. Lava. Waterfall, middle of E. side of site of Humeston Wood, Carrick Hills, 2 miles N.W. of Maybole, Ayrshire. S 27556. Lab. No. 1004. Anal. C. O. Harvey. *Sum. Prog. Geol. Surv.* for 1936, Pt. I, 1937, p. 86. Eyles and others, 1949, p. 137.

altered specimens, completely replaced by carbonate and clay mineral, are zoned from about An_{64} to An_{54} with a thin outer rim of composition about An_{64}; some crystals show repeated oscillatory zoning. Xenoliths of coarser, highly decomposed, igneous rock (?microdiorite) were observed in two thin sections (813, 50845A). A pebble (558) from the Old Red Sandstone conglomerate at Fochabers is indistinguishable, in thin section from some of the more altered specimens of the Gollachy Burn rock.

In view of the proportion of alkali feldspar in the base the rock is probably better regarded as trachyandesite or at least as intermediate between andesite and trachyandesite. This is confirmed by the relatively high proportion of potash recorded in the analysis (Table III) though some of the potash must be ascribed to the biotite of the rock. The silica content of the analysed rock is increased because of the small irregular patches of quartz. Geikie (1878, p. 435) has remarked on the close similarity of the Gollachy Burn rock with some of the lavas of Lower Old Red Sandstone age in Central Scotland. R.W.E.

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Chapter IX

PLEISTOCENE AND RECENT

Introduction

THE SOLID rock in the Elgin District is concealed in many places by varying thicknesses of till, sand, gravel, silt and clay deposited by the Pleistocene glaciers or by the meltwaters associated with them. Most of the till seems to have been derived from a westerly or north-westerly direction, being brought by repeated invasions of ice advancing down the Moray Firth, and only in the extreme south, mainly outwith the sheet, is there evidence of transport from the south. The latest incursion of ice from the Moray Firth, called the Elgin Oscillation in this account, was responsible for the deposition of the large spreads of sand and gravel which occur in all but the east and south-east parts of the area mapped. Towards the close of the Pleistocene the sea invaded parts of the lower ground that were not still ice-covered, and at a later stage, in post-Glacial times, the superficial deposits left by the ice were extensively reworked by a sea standing some 20 ft higher than at present. Above the level of marine action the glacial deposits have undergone a certain amount of fluvial erosion, and some of the depressions have been partly filled by alluvial deposits and peat. The continuance of change into more recent times is exemplified by the gradual exclusion of the sea from the Spynie depression, latterly assisted by artificial drainage. The sequence of these events is summarized below:

Post-Glacial	2.	Formation of storm beaches and raised beach features at 30 ft O.D. and below. Deposition of peat and alluvium
	1.	Low sea-level, growth of submerged forest at Burghead
Late-Glacial	2.	Decay and disappearance of ice mass in Spynie depression
	1.	Decay of Moray Firth ice, in part coinciding with a sea-level of about 80 ft O.D. Deposition of glacial sand, gravel, and silty clay (in part)
Glacial	2.	Elgin Oscillation (Fochabers Glacial Lake Stage) possibly with reworking of older tills. Deposition of glacial sand and gravel (in part)
	1.	Deposition of dark grey till, brown till, and till with diorite and gabbro erratics (the last mainly in area of sheets 85 and 96). Relationships not well defined, but probably several glacial episodes involved

Sub-Drift Topography

In the north the Spynie depression, probably excavated along a major fault, is infilled by drift, the removal of which would turn the Roseisle–Covesea ridge into an island. Geophysical and borehole evidence suggests that the deepest part of the rock-defined trough lies some distance north of the low ground formerly occupied by the Loch of Spynie.

The course of the Lossie takes it through two basins, now occupied by marine and river alluvium. The present-day Middle Lossie Basin, between New Elgin and the north end of the Glen of Rothes (Sheet 85), appears to have been cut into drift deposits which fill a hollow in the rock floor extending parallel to, and south of, the cornstone outcrop between New Elgin and the Boar's Head Rock. At the south end of the basin, the Blackhills Overflow Channel has been cut through at least 50 ft of drift into deeply-weathered conglomerate on the south side.

East of Elgin lies the Lower Lossie Basin, sandwiched between the Hill of Spynie with its low north-easterly extension through Scarffbanks and the cornstone ridge referred to above. West of Elgin, the alluvial flat of Mosstowie may be a westward extension of the Lower Lossie Basin.

Though the slope of the present alluvium and the terraces of the lower Spey is constant (about 16 ft per mile) it is evident that this regularity is superimposed on an irregular rock floor. North of Fochabers Bridge as far as Upper Dallachy the upper terraces are incised into Old Red Sandstone conglomerate, but south of the bridge the solid rock disappears under the alluvium for some two or three miles. The Spey and its tributaries are here cut into at least 60 ft of drift without reaching the rock head, and evidently cross the site of a hollow in the rock floor. Seawards, the rock surface falls away north-west of a line from Porttanachy to Upper Dallachy, and there are no further outcrops until the Boar's Head Rock is reached. Towards the east of the sheet, the ridge-and-trough topography merges eastward into the till-covered Buckie–Banff platform, and southward into higher ground. In the Burn of Cairnfield at Pathhead Wood, a depression in the rock has preserved dark grey boulder clay [421610–3], and it seems possible that this depression continues as a north-north-eastward-trending valley in the Core Burn between Drybridge and Linnhouse Wood, which is known to be bounded by solid rock on its east side.

At most points in the Elgin area where the till is stripped away, a glaciated rock pavement is exposed, but at one or two points the till rests on weathered rock. In the south-east, flags exposed below till in the Ardmachie Burn [405593] are decomposed to clay, and on the north-west slope of the Hill of Maud farther east (just off the area of the sheet) about 20 ft of quartzite largely reduced to sand are exposed in a recent gully. The conglomerates of the Middle Old Red Sandstone on Whiteash Hill and in the ground to the south-west are deeply weathered below the till.

Features of Ice Erosion

Owing to the pervasive drift-cover ice erosion is evident only on the Monaughty ridge, the Alves–Carden–Quarry Wood–Spynie ridge, and the Roseisle–Covesea ridge. Large-scale features are absent or hidden, though it is possible that the steep east face of the Knock of Alves originated by plucking. Glaciated pavements are well preserved on the siliceous sandstones of Carden Hill and Quarry Wood, with plucked surfaces confirming the east-south-easterly direction of transport indicated by the striae. At various other points striae have been noted beneath quarry overburden, but there are few records east of the Spey.[1]

[1] J. S. Grant Wilson noted dubious striations pointing S. 37° E. on polished quartzite on Stonyslacks hill top.

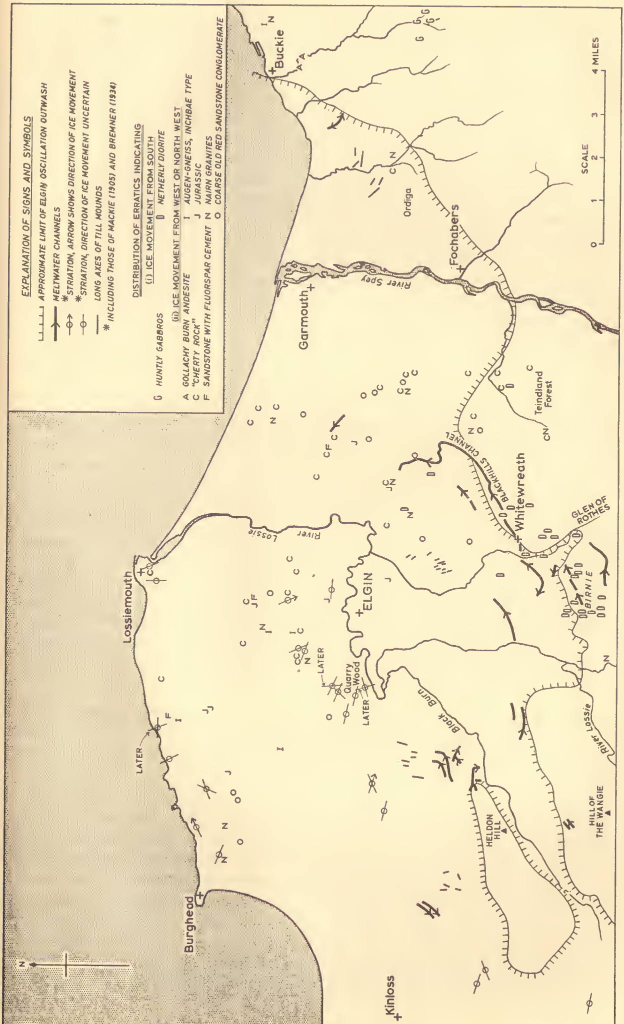

FIG. 15. *Glacial features of the Elgin District, striations, erratics, and meltwater channels*

The azimuths of striae recorded during the revision survey and by previous workers are shown in Fig. 15. Two major sets can be made out, trending respectively east-south-east and south-south-east. Though it is apparent that the east-south-easterly striae show a movement of ice from the west-north-west, agreeing with the lithology of the till itself (p. 91), the direction of travel indicated by the other set is not clear. Mackie (1901) and Bremner (1934) obtained evidence at Quarry Wood that the grooves begin sharply at the north end and become narrow and shallow towards the south, and the latter author took this to indicate ice movement to the north. The criterion is, however, ambiguous (Flint 1957), and it seems possible that the south-south-easterly striations could have been produced by ice moving inland from the coast during the last phase of glacial activity, the Elgin Oscillation.

Apart from the two major sets of striae already mentioned, various other directions, mainly towards an easterly point, have been mapped. A particularly good example of crossed striations was noted by Bremner (1934, p. 42) on cherty limestone at Inverugie, the travel direction of each movement being shown by miniature 'crag and tail' formation.

ERRATICS

With few exceptions the numerous and variegated erratics can be matched either with the local rocks or with formations cropping out to the west or north-west. The commonest erratics, in accordance with the composition of the underlying till, are Moine gneisses, psammitic granulites, and pelitic schists, followed by grey and pink granites. Old Red Sandstone blocks are distributed throughout and Permo-Triassic sandstones are frequent over, and to the south-east of their outcrops. Masses of fossiliferous Triassic sandstone, possibly erratics, were at one time exposed at Lhanbryde (Taylor 1920).

Within the confines of Sheet 95, three rock types have given rise to distinctive erratics (Fig. 15). Of these, the most widely distributed is the chert and cherty limestone from Stotfield, Inverugie and Spynie, boulders of which are found north of a line from near the coast at Cummingstown through Elgin to Lhanbryde parish. The localities are too numerous to be detailed here, but good examples may be seen at the following points:

(a) On the south side of Branderburgh, just above the footpath leading from Prospect Terrace to the bottom of the hill (250 yd E. 10° N. of the school)
(b) Near Spynie farm [230655], 250 yd due west of the graveyard
(c) At the roadside 450 yd NW. of Nether Meft [272642]

Blocks of the fluorspar-bearing sandstone from Hopeman or Halliman Skerries have been found in till near Ardivot [223670] and Parks of Innes [280640], and of the Gollachy Burn andesite at Mill of Buckie [423647] and Mains of Buckie [427646]. These three groups of indicator stones have clearly been transported to the east and south of their known outcrops.

The distribution of erratics from outwith the sheet have been summarized by Bremner (1934). Of these, material thought to have been derived from the reddish porphyritic granite at Park (Kinsteary) near Nairn has been seen throughout the district, and a few fragments of augen-gneiss of Inchbae type have been noted during the resurvey (Fig. 15). Of particular interest are the records of Jurassic and Cretaceous[1] erratics similar to those seen in the area of Sheet 96 to the east (Read 1923), many of which can only have been derived from Mesozoic outcrops at Brora and Ethie, or from the floor of the Moray Firth itself.[2] However, apart from an erratic underlying a field at Kaim, near Duffus [157678], which continues to yield blocks of shelly limestone, and two new localities of fossiliferous shale near Shempston (p. 92), little is now visible of the profusion of large Jurassic erratics reported by earlier observers, though small fragments of fossils and limestone are occasionally met with in the till. The famous erratic at Linksfield near Elgin (Brickenden 1851) is obscured, and there are no exposures of the belemnitic shales, clays and lignite noted at Lhanbryde and on the bed of the former Loch of Spynie by Duff (1842) among others. The larger Jurassic erratics represent rock masses transported *en bloc* by the ice, and as such are distinct from till formed partly of comminuted Jurassic strata.

In the extreme south-east of the area, erratics derived from the Huntly basic rocks can be seen at Hill of Menduff, conforming with the northerly limit of distribution mapped by Read (1923, p. 204). Blocks of a diorite like that at Netherly, on the west side of the Glen of Rothes, are scattered by the roadside south of Longmorn Distillery, just off the southern edge of the area of the sheet, and farther south are frequent constituents of the till on the higher ground on both sides of the Glen of Rothes. These erratics of southerly origin are clearly connected with the Upper or Northerly Drift (Read 1923) of coastal Banffshire.

TILL

INTRODUCTION

The till mapped in the Elgin District is divisible into dark-grey clayey till, and brown or red-brown, generally rather sandy till; both of these are derived from the west or north-west. In the extreme south as mentioned above there is evidence for glaciation from a southerly direction, the high ground on both sides of the Glen of Rothes being partly covered in grey or brown boulder clay with blocks of Netherly Diorite (Hinxman and Grant Wilson, 1902, p. 33). Since the deposits associated with this latter ice movement occur entirely in the area of the adjoining Rothes (85) Sheet they are not considered in detail here.

DARK-GREY TILL

A dark grey to grey-brown till has been found at a few localities, mainly in the eastern part of the area of the sheet, where it underlies the brown boulder clay. In the Burn of Cairnfield, hard dark grey till is seen near stream-level at a point 400 yd E. 30° S. of Pathhead Farm [418615] and can be traced in bank scars upstream for some 300 yd. The thickness seen above stream-level is no more than 5 ft, and there is a sharp, almost horizontal contact with the upper yellow-brown or red-brown till, for which a thickness of at least 20 ft can be inferred. Lithologically, the dark grey till is characterized by its colour and by its high clay content. The coarser material is dominantly psammatic granulite

[1] Cretaceous glauconitic sandstone has been recorded from a borehole on Lossiemouth Airfield.

[2] Details of faunas from these erratics, which include ?Rhaetic, Lower Lias, 'Middle Lias', 'Lower Oolite', Oxfordian, and Upper Greensand, are given by Judd (1873, p. 145 *et seq.*, and table 2). The fossils listed by Judd have not been traced.

and quartzite, followed in order of abundance by material from the local Dalradian, together with small quantities of calcareous sandstone, black slate, fine-grained limestone, andesite, sandstone of the Old Red Sandstone, and granite. Fragments of soft black shale occur in the finer fraction of the till, and the proportion of angular to rounded and frosted quartz grains is high. One sample of till yielded a small number of foraminifera. At the same locality a specimen of tbe upper brown till, 3 ft above the top of the grey till, is lithologically less diverse, with mainly sand size particles commonly of angular quartz. The rock fragments in the upper till are almost entirely of psammitic granulite, quartzite, and micaceous flags; foraminifera have not been found.

In tbe Core Burn, due east of the above locality and 750 yd W. 15° S. of Greenbank [442613], blue-grey, clayey till is exposed at the base of a 30-ft high bank in a stream scar. A stone count confirmed the dominance of psammitic granulite, quartzite, and local Dalradian rocks, and material referable to the sandstones and cornstones of Old Red Sandstone age was found, together with red granite, fine-grained white limestone, and numerous small fragments of black shale. The till also contains sparse shell fragments and an abundance of foraminifera.

West of the Spey, grey till is exposed in the Stripe Burn [32536512] west of Garmouth, where the following section is seen:

(c) 6–8 ft brown, micaceous till, very sandy, containing many well-rounded pebbles and cobbles of quartzite and psammitic granulite
(b) Pale yellowish-brown till (10 YR 6/2) containing numerous well-rounded pebbles
(a) Stiff to hard olive-grey till (5 Y 4/1–5 YR 5/2)

The till (b) is evidently an oxidized portion of (a), and masses of this lower till are incorporated in (c). The highly irregular contact between the two tills can be traced from where the burn debouches on to the beach gravels for several yards upstream beyond whicb only brown till is visible. Lithologically the olive-grey till is characterized by a high clay fraction, probably derived from black shale, numerous pieces of which are visible among the coarser fragments.

Dark grey-brown boulder clay with foraminifera and belemnite fragments has been intersected by boreholes on Lossiemouth Airfield below the normal brown boulder clay, and bluish boulder clay with Liassic fossils was formerly seen at several points east and north-east of Elgin (see pp. 92–4). Dark grey till with Jurassic material occurs below brownish-grey till in the Geological Survey East Mains Borehole [20436671]. Some of these examples might be referable to the dark-grey till, either *in situ* or as transported masses in the upper till.

There is little doubt that the dark grey till in the Core Burn and in the Cairnfield Burn belongs to the Sbelly Boulder Clay described from the adjacent ground (Read 1923, p. 193 *et seq.*), and was transported by ice moving in a soutb-easterly direction over the floor of the Moray Firth. Tbe blue-grey clayey till of the Stripe Burn resembles the boulder clay with Jurassic fossils observed at several points farther east. Though Read concluded that tbe Shelly Boulder Clay is part of the Lower or South-easterly Drift of Banffshire, the exposures in the Elgin District suggest that it is in part overlain by the normal red-brown facies of this drift, and thus that more than one period of glacial deposition might be involved. A similar argument also might be advanced to explain the relationship of the dark till with Jurassic fossils to the brown till.

BROWN BOULDER CLAY

Till deposited by ice moving from the west or nortb-west is spread over the whole sheet, particularly on bigb ground where tbe fluvio-glacial deposits and later alluvium are thin or absent. The thickness is variable, often of the order of 10 to 15 ft, but in a few places such as the Blackhills Overflow Channel, and on the east bank of the Spey south of Fochabers, thicknesses in excess of 40 ft have been seen. The colour of the till and its lithological composition vary to some extent from place to place, partly in accordance with the nature of the underlying rock. On tbe Roseisle–Covesea ridge, and in the Quarry Wood area, the till is yellow-brown to greyish orange, and the sand fraction exhibits numerous frosted millet-seed grains derived from the underlying sandstone. Some exposures of till on and to the east of the Middle Old Red Sandstone districts show a transitional or sharp contact between red below and yellowish-brown above. A percentage of material derived from the Dalradian quartzites and flags becomes appreciable towards the eastern edge of the sheet. However, with a few exceptions, some of which are detailed below, the dominant material in the coarser fractions is derived from the Moine areas to the west, and the till is sandy rather than clayey. Other fragments frequently found are granite, quartz porphyry, and occasionally Jurassic limestone. At some exposures masses of sand and gravel, bedded or unbedded, occur in the till, and, as is often the case, there is in places a transition from unstratified to stratified drift.

Much of the ground swathed in till is characterized by low relief and smooth slopes, but in several places ice-moulded forms are preserved. East of the Spey at Beldornie Hillocks [377620] there are a few small ridges with longer axes directed south-east or east-south-east and, near Elgin, about two-thirds of a mile south of Linkwood [233613], a number of till ridges (drumlins) are aligned between south and south-east. In these examples tbe ridges appear to be oriented roughly parallel to the supposed direction of ice movement, but on the opposite side of the River Lossie in the neighbourhood of Mosstowie somewhat similar ridges trend south-south-west. In all three cases there is some association of the till ridges with ridges and mounds of sand and they could perhaps be partly features of ice-disintegration rather than entirely ice-moulded forms (Gravenor and Kupsch 1959).

Details

Roseisle-Lossiemouth. In the extreme west of the Roseisle–Covesea area a few feet of bouldery till underlie raised beach deposits at Burghead Coastguard Station. On Clarkly Hill up to 12 ft of stiff, brown, sandy boulder clay with clayey lenticles crop out in the old quarries, and similar material about 7 ft thick is exposed at the east end of Masonhaugh Quarries immediately to the north. On the west side of Clarkly Hill 400 yd due S. of Burghead Transmitting Station, a quarry [12456827] shows about 10 ft of unusually clayey, brown till resting on sandstone. Boulders of the Burghead sandstone, Moine schists and granulites and various granites are present, and it was here that Bremner (1934, p. 41) noted a boulder of Inchbae-type augen gneiss. The till matrix is composed of smaller fragments of the same materials together with Old Red Sandstone debris, and the sand fraction contains many well-rounded frosted sand grains.

East of Masonhaugh Quarries till is seen in the railway cutting north of Cummingstown, but the best section in this neighbourhood is at Greenbrae Quarry [138692], where a thickness of about 15 ft of yellow- to pinkish-brown, sandy till, with a few intercalated bands of sand and gravel, is exposed. The till, which lies on a striated sandstone pavement, contains few large stones, but yields fragments of granite, psammitic granulite, grey calcite-mudstone, sandstone, ferruginous chert and shelly Jurassic limestone. In the centre and northern part of the quarry, the till has been removed by the late-Glacial sea, and beach sand and gravel rest directly on the striated platform; the striae trend N. 60° E.

South of Hopeman reddish boulder clay to a depth of 8 ft, overlain by 6 ft of less coherent stony material, was formerly seen at a limestone quarry [151687] NW. of Inverugie, but solid rock reaches the surface on the ridge which extends from here to Clarkly Hill. From Inverugie to Oldtown of Roseisle the till is overlain by patchy sandy gravel and a foot or two of blown sand. A small quarry at Bank of Roseisle [152668] shows only a thin bouldery deposit on pebbly sandstone, but at Kaim [157678] several feet of very sandy till were seen below 2–3 ft of sand in an excavation. The Jurassic erratic at this locality (400 yd E. of the school) has already been mentioned (p. 89): Judd (1873) considered it to have been derived from Lower Liassic strata.

A narrow strip of sand separates the Covesea till area from that described above. Most of the higher ground here has probably only a veneer of drift, but on the flanks the cover thickens, up to 15 ft being noted at Clashach Quarry [163702] and 30 ft in a borehole near Plewland [177697]. South-west of Covesea Skerries Lighthouse the raised beach features are partly eroded into till. At Lossiemouth a thickness of 1–5 ft of sandy boulder clay overlies a striated rock surface in the old south-facing sandstone quarries. As mentioned above, dark grey-brown and grey boulder clay has been located at several points below raised beach deposits during boring on Lossiemouth Airfield. This material has a notable clay fraction, and besides the usual fragments of psammitic granulite, granite and sandstones derived from the Old Red Sandstone and Permo-Triassic, contains fragments of fine-grained, dark grey silty flagstone and shale (probably Jurassic). Fragments of oolitic limestones and belemnites also occur.

South of the Covesea ridge and north of the Spynie basin, boulder clay appears at a few points. The most westerly exposure is in a pit in a gravel mound 400 yd W. of Phillexdale [168679], where about 4 ft of till is seen below 4 ft of sand and gravel. Sandy boulder clay with the usual stone content occurs on the hill-top north-north-west of Shempston [184683]. Here erratics of dark grey shale with a few shells occur at two points, one at the south end of the small plantation (Grant 1960), and the other 60 yd WNW. of the north-west corner of the same plantation. The artificial mound on which Duffus Castle stands may be founded on till. A good exposure [22366677] is to be seen in the old sea-cliff 350 yd SW. of Ardivot [225671]. At this point 15 ft of till with large included masses of contorted lacustrine silts and a few boulders of pebbly sandstone are partly overlain by interbedded sand and clay. This locality has yielded a boulder of fluorspar-bearing sandstone like that found near Hopeman (p. 60).

Spynie, Quarry Wood, Carden Hill, Monaughty Forest. North of Elgin, boulder clay is exposed on the Hill of Spynie and at Linksfield, and west-south-west in an almost continuous strip from Findrassie and Bishopmill to Quarry Wood, Knock of Alves, Carden Hill, Burgie, and thence to Monaughty Forest on the south edge of the area of the sheet. On the Hill of Spynie a small area of bouldery till is irregularly distributed on a glaciated surface of Triassic sandstone, the till thickening eastward. In a field west of Pitgaveny [239652] a Jurassic erratic was seen by Duff (1842), and blue clay with limestone concretions was recorded during the primary survey at the edge of the loch north of Spynie Palace and also at a point 450 yd E. 32° S. of Spynie farm [229655]. The obscured erratic at Linksfield (Judd 1873, p. 148) is now represented only by a few blocks of limestone in the floor of the quarry. There is little exposure of the pinkish-brown, silty till which covers the rest of the hill.

At the Muir of Myreside [210650], the stony till yields many boulders of pebbly sandstone derived from the underlying rock, together with sandstones derived from the Triassic and Upper Old Red Sandstone, psammitic granulite, pelitic gneiss, pink porphyritic granite, and cherty limestone. Reddish till some 15 ft thick is exposed at Bishopmill Quarry [208637] and intercalations of sand and gravel were observed during excavations for a new road south and west of the quarry.

On Quarry Wood Hill the boulder clay, which only partially veneers the solid rock, is very sandy, stony and incoherent, and is often difficult to distinguish from the much-broken and weathered sandstone which overlies the fresh rock in places. The drift thickens northwards, and 12 ft of red-brown boulder clay are seen at the old quarry [189640] 900 yd ESE. of Quarrywood School. North and north-west of Quarrywood School, the gently sloping ground is formed of sandy clayey till with a variable pebble content, obscured at some points by thin spreads of sand and gravel.

Siliceous sandstone forms the ridge extending westwards from the Knock of Alves to Carden Hill, and the fine glaciated pavement which can be seen where the rock appears through the drift has already been noted (p. 86). In contrast to the incoherent superficial material covering parts of Quarry Wood Hill, the till here takes the form of a stiff reddish-brown sandy boulder clay with prominent angular fragments of psammitic granulite, while boulders of quartz-porphyry, mica-schist, sandstone, conglomerate and granite are exposed at the surface.

From Carden Hill towards Alves Wood the till-covered ridge continues and merges with the large area of boulder clay at the west end of the Mosstowie flat. In a gravel pit 320 yd NE. of Morayscairn [106609] about 6 ft of sand and gravel overlie 9 ft of red-brown sandy till with a lens of sandy gravel. The till contains the usual dominant stones of quartzite and psammitic granulite (50 per cent) accompanied by significant quantities of sandstone and granite (15 per cent each) and smaller amounts of schists and basic igneous rocks (microdiorite, epidiorite and hornblende-schist). South of Lachlanwells [131609] the stream has eroded through about 15 ft of hard reddish till, and 350 yd SE. of the farm a gravel pit transecting a till mound shows about 6 ft of till overlying bedded sand and gravel. In the Burgie area solid rock has been quarried at a number of points, but 500 yd S. of the distillery [095602] 20 ft of brown sandy till is exposed in the Burgie Burn, and here, as well as in a till exposure 300 yd E. of Burgie Castle [094593], the dominant fragments are of psammitic granulite with a little schist and granite. The till in this neighbourhood forms low mounds, which near Wester Lawrenceton [076583] trend S. 20° E., oblique to the azimuth of the striae nearby.

The northern slope of Heldon Hill and Monaughty Forest is mantled in thick compact till similar to that described above, and in places is covered by thin sand and gravel, which reaches a thickness of 9 ft at one locality [135596]. On the steep south side of Heldon Hill, sections show the till to be mixed with hillwash and overlain by unconsolidated scree derived from the crags at the top of the slope. At Crossley Clay Pit [166575] the till pebbles are largely of Moinian psammites (64 per cent), and only 2 per cent are of sandstone.

Area between the River Lossie and River Spey. East of the River Lossie the higher ground along the south edge of the district is largely covered in boulder clay of the East-south-easterly drift, and patches and mounds of similar till appear from under the meltwater deposits north-eastwards to Garmouth. In general it can be said that the till becomes more stony towards the south and south-east, and that the pinkish-brown colour intensifies to a red shade like that of the underlying Middle Old Red Sandstone conglomerates.

Just beyond the margin of the ground shown on Sheet 95, south of Dykeside [209588] there are numerous exposures of stony, red, sandy till with granite boulders in Hillhead Wood, and farther east, a wide area of generally smooth but locally hummocky till-covered ground enters the district at Blackhills and Cranloch [285587]. About a mile north-west of Longmorn Station and 400 yd S. of Burnside [223593] scars in the left bank of the stream show 20 ft of medium-grained sand overlying 15 ft of red sandy till, and 200 yd ESE. of the same farm a scar on the right bank reveals 6 ft of gravel on 9 ft of till. Sections in the Blackhills Burn south and south-west of Blackhills House [271585] south of the sheet margin show that, though much of the till is a structureless red boulder clay, there are intercalations of bedded sand, silt and gravel in places. A thickness of at least 50 ft can be inferred for the till in parts of the channel of the Blackhills Burn.

North of this ground, to the east and west of Birkenhill Croft [225600], a thin and discontinuous mantle of fluvio-glacial sand partially obscures the numerous drumlin-like till ridges with a pronounced north-north-west orientation which can be followed as far north as Linkwood [233613]. At New Elgin the smooth contours are resumed where the till shows above the fluvio-glacial deposits, and varying thicknesses up to 22 ft in a water bore near the Rothes road [221614] have been recorded. Where exposed, the unweathered till is a pinkish brown, sandy boulder clay with relatively few large boulders, and the colour may be altered to yellowish-brown by hydration and oxidation, and to grey under water-logged conditions.

In the Coxton area, about a mile west of Lhanbryde, some half a square mile of ground is underlain by till. In a drain-cutting 500 yd NW. of Wester Coxton [256603], a thickness of about 8 ft of reddish-brown to grey silty till is exposed, and boulders of granite, sandstone and conglomerate are scattered through the fields nearby. South-east of Lhanbryde, till has been observed at a few points underlying the glacial and fluvio-glacial gravels. A particularly good section can be seen in the scar [27725977] cut by the continuation of the Blackhills Overflow Channel, 600 yd E. 30° S. of Hatton [273601], where 10 ft of fine-grained buff sand and coarse gravel rests on, and tongues into, 10 ft of pebbly boulder clay.

The stretch of country running north-east from Lhanbryde and the River Lossie almost to the Binn Hill, has a confused moundy topography of bedded glacial sand and till, probably resulting from the decay of dead ice. In places the mounds are isolated by tracts of alluvium. Normally the till is badly exposed, but a section about 20 ft high through a till mound can be seen in an old quarry [248618] by the Elgin to Fochabers road 1300 yd E. of Waukmill, and another small excavation 400 yd W. 33° N. of Nether Meft [262642] exposed 6 ft of reddish till overlying current-bedded red and buff silt and clay. At the former locality the till contains many cornstone boulders. About 350 yd due E. of Jointure [265648], till with numerous angular fragments of hard deep-red sandstone was formerly exposed in a drain-cutting. Jurassic erratics have been seen in the Lhanbryde–Urquhart district (e.g. Judd 1873, p. 156 and p. 177), and dark bluish boulder clay with fragments of Jurassic shale and sandstone was formerly exposed below the railway embankment 750 yd W. of the road bridge at Urquhart Station. Boulders of chert and cherty limestone probably derived from the Cherty Rock are common in the boulder clay areas, together with boulders of Moine psammitic granulite, Old Red and New Red sandstones and limestone.

On the west side of the Binn Hill, mounds of till accompanied by erratic boulders of grey granite, Triassic sandstones, and cherty limestone, occur in the fields east of Speyslaw Farm [285667]. The till is not far below the surface at Nether Unthank, where it was formerly seen in a well east of the farm buildings. Eastwards towards Garmouth the back-feature of the post-Glacial raised beach is cut into till between Gladhill and Winnyhaugh [336651]. The section in the Stripe Burn has already been described (p. 90), and the upper brown, very sandy till is particularly well exposed in the old cliff due west of Winnyhaugh.

Good sections of superficial deposits have been exposed south and west of Fochabers by the downcutting of the River Spey and its tributaries. About a mile south-west of Balnacoul Wood, a number of sections occurring in the Red Burn show reddish-brown till with large masses of intercalated sand and coarse gravel. About 170 yd E. 30° S. of the railway bridge [306576], the following sequence is exposed: sand, increasing in thickness to the north-east; brown clay, structureless above, finely laminated with

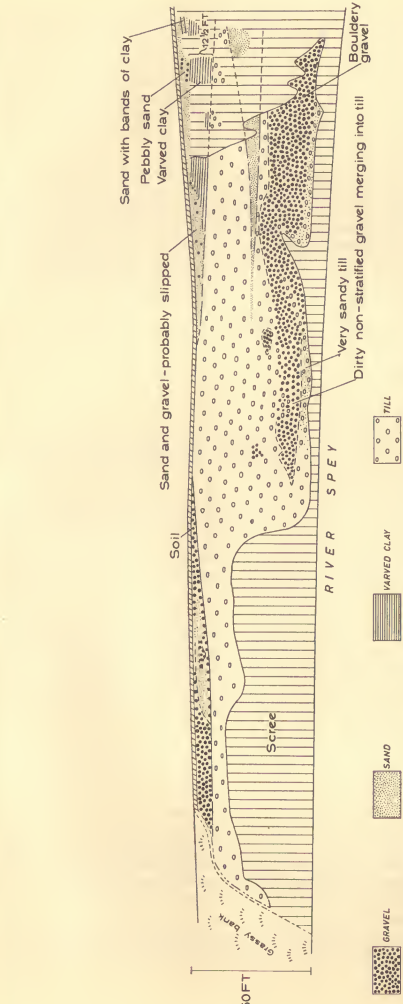

FIG. 16. *Sketch of meander scar on east bank of River Spey [340575], south of Fochabers. Till with masses of sand and gravel is overlain by varved clays and sands of Fochabers Glacial Lake to right and by old alluvial gravels of Fochabers Burn to left*

reddish laminae near base 2 ft 6 in; on reddish brown till with irregular masses of sand 15 ft. Another scar 100 yd upstream shows a similar section: soil; sand 1 ft; light brown clay (lower half laminated) 4 ft; brownish red till 2 ft; on sand and gravel 10 ft. In both cases the contact between the till and clay is an almost flat surface. About 15 ft of till with a band of disturbed sand and gravel are well exposed at a point 530 yd due W. of the railway bridge over the Red Burn, and other examples of the same nature can be seen in the terrace feature east of Crofts of Dipple (323589). On the left bank of the Spey 500 yd SW. of Fochabers Bridge, about 15 ft of very sandy till overlying the Middle Old Red Sandstone can be seen in the river cliff.

Area east of the River Spey. On the east bank of the Spey, a few hundred yards beyond the southern edge of the area of Sheet 95, an exceptionally extensive section of glacial drift some 60 ft high is exposed in a meander scar [340575] south-west of Castle Hill. The greater part of this deposit is reddish-brown till with intercalated fine to bouldery gravel (Fig. 16). As in the Red Burn sections the till is overlain by laminated (varved) glacio-lacustrine clay (see p. 105). The thick boulder clay evidently underlies Castle Hill and is again exposed in the Burn of Focbabers, where the following section can be seen on the left bank, 400 yd E. 85° S. of Fochabers School:

	Ft
Coarse- to fine-grained sand, cross-bedded with occasional thin pebbly bands	14
Gravel and pebbly sand	0–2
uneven surface	
Reddish-brown till with boulders of granite and quartzite	10
Red till (lower part concealed by talus)	27

On the left bank, 600 yd upstream from the above, the following is exposed: brown till 12 ft; on red till (partly obscured by talus) 23 ft. The boundary is sharp, with a tongue of red till extending into the brown.

Between these two sections a number of exposures can be seen showing contorted bands and lenses of sand and silt enclosed in the till. The red till is clearly derived from the underlying Middle Old Red Sandstone. It should be remarked that the boundary between the brown and red tills is not always as sharp as in the above sections. East of the Burn of Fochabers the till thins rapidly and red conglomerate, patchily overlain by red till, is exposed on the slopes of Whiteash Hill.

North of Fochabers the lower Spey terraces on the right bank of the river are cut into Middle Old Red Sandstone conglomerate and sandstone overlain by till and late-Glacial fluviatile sand and gravel. In a gully at Gowktree Wood, 600 yd E. 35° S. of Byres [356623], the following section occurs: terrace gravel 8 ft; boulder clay, pinkish (10 R/5) below, greyish above 10 ft; on conglomerate 12 ft+. The boulder clay is sandy, and the fragments recorded are almost all quartzite and psammitic granulite with a few of granite and flags.[1]

Between the Spey and the Burn of Tynet lies the hummocky terrain of the Ordiga area. Mounds of sand and till merge into one another, and though Bremner (1934, p. 34) thought the hummocks to be a terminal moraine, it seems more likely that the sand-mounds originated during the decay of stagnant glacier-ice. An interesting section is exposed in a pit on the north bank of the stream 750 yd due E. of Boghead [355593]. Here a thickness of about 10 ft of variegated clayey, sandy, and open-textured ill-sorted morainic gravel is seen, partially obscured by talus, with bedding inclined at about 20 degrees to the south. The material has evidently been deposited adjacent to glacier ice occupying the Deer Park area. At Ordiga, a pit on the north side of the A98 Fochabers–Banff road, 1200 yd SW. of Tulloch [383609], shows sand and silt partly enveloped by till.

[1] The nearest point where Dalradian flags are exposed is some three miles to the south-east, but the fragments in the till may have been secondarily derived from the Middle Old Red Sandstone conglomerates.

In the upper reaches of the Tynet Burn and on the high ground stretching east to Hill of Stonyslacks and Hill of Menduff, the covering of till is probably generally thin, and in some places is altogether absent. A thickness of about 10 ft of red till is exposed at the top of the high bank of the Aulrothie Burn, 850 yd S. 60° W. of Braes of Enzie [393597], and a similar thickness in the Tynet Burn 750 yd E. 5° S. of the same farm. In the extreme south-east corner of the district, yellow sandy till at least 5 ft thick has been noted on the south-east slope of the Hill of Stonyslacks.

Below the Bridge of Tynet, the Tynet Burn cuts through the drift into solid rock, and exposures of till can be seen at various points as far as the Mill of Tannachy [382637]. At Lower Mills of Tynet [383619] between 20 and 25 ft of red, sandy till with boulders of white sandstone and granite are exposed in the right bank, and a detailed examination of a sample showed some fragments of Permo-Triassic sandstones and Dalradian flags in addition to the preponderant granulite and quartzite. Good sections of till occur on the left bank of the burn south of the Mill of Tannachy where there is up to 15 ft of red sandy to clayey till with blocks of the underlying sandstone, overlain by sand and gravel at some points.

The next stream to the east, the Gollachy (Buinnach or Cairnfield) Burn shows few points of interest other than those already mentioned (p. 89). About 650 yd S. 3° W. of Buinnach [420605], a section in a tributary burn reveals brown till overlying dark grey boulder clay derived from the local flags. A similar section in the Burn of Buckie farther east can be seen 850 yd W. 40° N. of Mains of Buckie [427646]:

	Ft
Thin sand	–
Pink sandy till with numerous well-rounded stones. Fragments mainly granulite, quartzite, granite, and flags with a few andesite, porphyry, Triassic and Old Red Sandstone sandstones	15
Passes down into	
Grey till composed almost entirely of decomposed micaceous quartzite	9
Decomposed micaceous quartzite	3

At the Mains of Buckie itself a good section on the left bank of the stream shows 15 ft of red till with boulders of pink granite, white and red sandstone, amphibolite and Gollachy Burn andesite, and a number of good exposures with up to 15 ft of red till resting on Cullen Quartzite can be seen at the top of the old sea-cliff between Buckie and Portessie.

Inland, along the east edge of the ground shown on Sheet 95, the low ground of coastal Banffshire is largely mantled in reddish boulder clay with intercalations of gravel. At Drybridge, at the junction of the Core and Letterfourie burns, red and yellow sandy till with gravelly bands is seen in stream scars in the 30-ft high bank. Boulders of chert, pink augen-gneiss, and quartzite have been observed. The possibility that a drift-filled channel occurs here has already been discussed (p. 86).

Meltwater Deposits

INTRODUCTION

Water-sorted sands, gravels, silts and clays cover large areas of the Elgin District. Apart from the sand and gravel bands and lenses within the boulder clay, which probably contribute little to the total area mantled by this material, most of the stratified sediment was transported and deposited by and in the meltwaters derived from the decaying ice. Though the meltwater deposits and the raised beach alluvium are clearly separable on the coast between Buckie and Burghead, in the Kinloss area and parts of the Spynie basin the distinction is less certain.

A characteristic feature of much of the water-sorted drift is its moundy nature, though in some areas terraces and plateau-like forms predominate. Where sections occur in the mounds the deposits are seen to be of cross-bedded sand and gravel, often with silt and clay bands and laminae. The bedding is seen to be disturbed and faulted at a few localities, but at others there is little evidence of post-depositional disturbance. Moundy sands interspersed with plateaux of lacustrine sediments and irregular hillocks of till are characteristic of the country north of a line from Monaughty Forest to Binn Hill, and seem to have formed during the decay of ice *in situ* following the Elgin Oscillation. It is difficult to account for the formation of all the mounds and plateaux on the hypothesis of deposition of sediment on wasting ice, and it is likely that some of them were accumulated sub-glacially in the manner described by Gjessing (1960).

The fluvio-glacial and glacio-lacustrine sediments are often pitted by kettle-holes, depressions caused by the melting of masses of ice after burial by sediment. Such kettleholes vary in size from a few yards to hundreds of yards across, and assist in distinguishing glacial meltwater deposits from recent alluvium. Their presence also shows that much of the topography has been little modified since the disappearance of the ice.

In addition to what are primarily constructional landforms, mention must be made of the erosional features produced by the meltwater rivers, the overflow, marginal, sub-marginal and sub-glacial channels which are frequently associated with the fluvio-glacial spreads. Of the larger overflow channels, the Black Burn valley west of the River Lossie, and the Blackhills channel farther east carried a considerable volume of meltwater at various stages in the glacier-retreat, and parts of the Spey valley also functioned as overflow channels at an earlier period (Bremner 1934, pp. 35–37). Smaller channels, marginal and sub-marginal to the ice-sheet, occur on Heldon Hill.

DETAILS

West and south-west of Elgin. A large area lying between the post-Glacial storm beach deposits on the coast and the boulder clay slopes of New Forres, Alves, and Quarry Wood is underlain by glacial sand, gravel, silt and clay. In places the landforms resulting from the decay of the ice may have been modified by the sea during late-Glacial times, but in other areas there is little evidence of marine action above the 30-ft level. Features attributable to the late-Glacial seas in the neighbouring Nairn area are well developed only at few localities (Ogilvie 1923) in contrast to the marked post-Glacial marine features.

South-west of Tarras [062597] moundy gravel deposits near Wester New Forres pass into more sandy sediment to the north. East of Tarras are further extensive deposits of fluvio-glacial gravels which have an almost plane surface descending from about 114 ft O.D. to 100 ft O.D. along the line of the A96 road north of Burgie Distillery. These gravels take on a moundy form a little farther to the north-east. A patch of glacio-lacustrine clay has been mapped at Hillhead [071598] and another a mile to the east is separated from the till-covered ground by a marginal channel sloping down to Scotsburn [087601]. Two marginal spillways, each a third of a mile long, occur north and south of Morayscairn [107609].

Glacio-lacustrine silty clay and silt cover an appreciable area in this part of the sheet and give rise to a specific soil association (Grant 1960, p. 42). The silts and clays vary in colour, being red, brown, yellow-brown or grey. They are clearly interbedded with the glacial and fluvio-glacial sands and gravels. The outcrops of silty clay occur at differing heights, those at Alves and Carden for instance being at or above the

100-ft contour, and that at Earnside (which is kettle-holed) at and below 50 ft O.D. Other localities where silty clays have been mapped are west of Lower Hempriggs, north-west of Coltfield, and at Spindlemuir and Orchardfield. At Rosehaugh Farm [166644], there is a strip almost two miles long and a thickness of 15 ft is reported to have been seen at the farm itself. At a point 320 yd due S. of Bridgend Farm [149661] an excavation showed the following; tough brown clay with a few pebbles 3 ft; clay, silt and sand bands 6 in; on yellow micaceous sand with gravel lenses near top 4 ft+.

A prominent topographical feature in this part of the district is an almost flat-topped ridge, the Hempriggs–Coltfield Ridge. It extends for one and a quarter miles, curving from south-north at Grange Hill (now an isolated mound) to east-north-east between Miltonhill [100630] and Coltfield [117637]. Another low fluvio-glacial ridge extends from Kirkhill [126638] to Standingstone [137644], east of which it grades into undulating topography. Grange Hill reaches 120 ft O.D., and the almost plane surface of the ridge falls away from just above 100 ft east of Brodie House [093627] to 50 ft at Coltfield. The south side of the ridge rises steeply above flats at about 30 ft O.D. and may be an ice-contact slope; the north side slopes away more gently, though a break in slope just below 50 ft may be a late-Glacial beach feature. On the south slope of Grange Hill, coarse-grained brown sand with a few boulders is seen in an old sandpit, and at Miltonhill 26 ft of cross-bedded sand is exposed. In a sandpit 200 yd SE. of Upper Hempriggs [103635], the following section is exposed on the steep south face of the ridge, the bedding in part conforming to the slope of the hillside: brown boulder clay 1–2 ft; on sand and silt with gravel lenses and wedges and cross-bedding dipping north and east 30 ft. In the latter, narrow fissures are filled with sandy clay, and balls of rock flour occur in the sand. About 70 yd NE of Upper Hempriggs, another sandpit shows: coarse brown sand and gravel 0–1 ft; sandy brown boulder clay 2 ft; on intensely contorted reddish silt and sand 10 ft.

It is probable that the sediments which form the ridge were carried by meltwater flowing from high ground to the south, and were deposited in a wide chasm in the ice, possibly a crevasse enlarged by ablation. The feature could, therefore, be the remnant of a kame terrace, subsequently modified to a ridge-like form by marine erosion.

North-east of Coltfield, an area of low sandy mounds interrupted by peaty flats at about the 30-ft level extends to the College of Roseisle. A section formerly seen in a mound just east of Buthill [133658] showed fine-grained sand with a few clayey and ferruginous partings. About 400 yd SW. of Inchkeil [143657], a kettle-hole is preserved at 30 ft O.D. and it is thought unlikely, therefore, that the deposits in this neighbourhood have been greatly modified by marine action. Though Ogilvie (1923) suggested that the sand and gravel ridges of Spindle Muir to the east were built up by the sea, they have none of the regularity normally associated with such deposits, and are more likely to be moundy glacial drift. At a pit 400 yd S. of Bridgend the following section is seen; blown sand with rootlets 2 ft 6 in; old soil with gravel pockets 9 in; on coarse-grained yellow sand with scattered pebbles, gravelly near the top 10 ft 6 in. This pit is only a short distance south of the exposure of glacio-lacustrine clay noted earlier. A little to the east the pebbles lying at the surface have been polished by drifting sand, and well-formed ventifacts can be collected.

South of the Carden Hill–Quarry Wood ridge a hummocky terrace extends from Easter Cloves [145618] eastwards to near Scroggiemill [174627], where it has been modified by the River Lossie. The terrace is best defined at its eastern end, but from a point west ofAldroughty [185623] to the Knock of Alves, its surface is characterized by kettle-holes and by west-north-west trending ridges. At a sandpit 450 yd ESE. of Knock Farm [166627], the following section was noted: sand and bouldery gravel with boulders up to 4 ft across 4 ft; on bedded sand 15 ft.

In a sandpit 300 yd WSW. of Oakwood [186627] 20 ft of sand with bands of fine and coarse gravel are exposed. That part of the terrace abutting against Quarry Wood Hill is more gravelly than the outer parts.

West of the River Lossie, on the south side of the Mosstowie flats, there is a series of gravel mounds covering a triangular area enclosed in the bend of the Black Burn upstream from its confluence with the River Lossie. An exposure 150 yd S. of Lochinvar [182617] shows 10 ft of coarse gravel overlying 6 ft of pebble-free sand.

From Upper Whitefield [172606] a narrow belt of gravels, largely in the form of north-north-east-trending esker-like ridges extends westwards for over a mile, and appears to have been deposited by water flowing in marginal channels which drained from west to east along the north slope of Heldon Hill. The channels which in places are represented by only one wall, were eroded into till by meltwater flowing at the side of stagnant ice resting against Heldon Hill. On turning to flow northwards (possibly into crevasses enlarged by ablation) the meltwaters deposited the debris which forms the esker-like ridges (cf. Mannerfelt 1945, fig. 26, p. 73).

On Heldon Hill itself there are a number of steep-sided deep dry channels which are entrenched some 60 to 80 ft, commonly into Moinian quartzite. The deepest channel starts at about the 600-ft contour, 1650 yd S. 18° W. of Wester Hillside [154603], descends steeply eastwards, and, after being joined by another steep-sided channel from the south, crosses the present watershed and turns southward. Other channels exist on the south side of Heldon Hill. Somewhat similar phenomena have been described elsewhere (e.g. Mannerfelt 1945: Mitchell and Mykura, 1962, p. 115), and it seems that such channels could have been cut by subglacial or marginal rivers at a time when Heldon Hill stood out as a nunatak.[1]

A well-marked terrace skirts the side of Heldon Hill from south of Miltonbrae [175602] to a point north of Netherbyre [152580]. The terrace falls gently from about 173 ft. O.D. eastwards to 130 ft near Miltonbrae, and is surmounted by gravel mounds at one or two points. For the most part it is composed of slightly imbricated boulder gravel with a small percentage of coarse gritty matrix. The boulders, which reach 2 ft in diameter, are mainly of Moine granulites with small amounts of granite, pelitic schist and sandstone. It is possible that some of the material forming the terrace was initially derived from the Heldon channels mentioned above, and was then redistributed by meltwater flowing down the Black Burn valley at a later stage.

To the south of the Black Burn there occurs a series of marked stepped fluvio-glacial terraces, composed of sand or gravel. One terrace a little above the 200-ft contour can be traced from 200–300 yd south of Foresterseat [161580] eastwards for some two miles, but the correlation of the remnants of the lower terraces, which have been dissected by the Black Burn, is less certain. A number of small channels, at present dry, run from one terrace to another, starting on a higher terrace as shallow depressions, and deepening rapidly, cut through the outer margin of the higher terrace to debouch on to a lower terrace. Such channels do not erode the lower terrace, but in some cases deposit a small alluvial spread at the point of debouchment. Towards the River Lossie the lower Black Burn terraces merge into more hummocky terrain. Though there is little doubt that the terraces were formed by water flowing east-north-east down the valley, it is not clear whether they were deposited as kame terraces marginal to wasting glacier ice or whether they were outwash spreads discharged from ice standing upstream (Bremner 1934, pp. 35–6).

Roseisle to Hill of Spynie. The major areas of meltwater-sediments in this district lie south of the Roseisle-Covesea ridge and for the most part form gently undulating topography. On the north side of the Spynie alluvium, a belt of glacial sand and gravel with patches of glacio-lacustrine silt and clay stretches from Kaim of Duffus almost to Sweethillock. Much of the country is well below the 100-ft contour, and it seems likely that the deposits below the 50-ft contour at least have been reworked to some extent by marine action.

[1] These channels may have been initiated during a glacial phase pre-dating the Elgin Oscillation.

From Kaim to Duffus the undulating topography is well seen. A sand and gravel mound at Phillexdale is flanked to north and south by silty clay. In an old roadside quarry 430 yd W. of Phillexdale a thickness of 4 ft of bedded gravel is seen overlying 5 ft of brown till. The strip of clay south of Phillexdale has been classed by the Soil Survey (Grant 1960) with the carse-type clays which occur at lower levels. Since the clay strip is not associated with any alluvial flat but gives rise to undulating topography like the neighbouring sands and gravels, a glacio-lacustrine origin is more likely. Most of this ground is below the level of the late-Glacial beach flat at about 80 ft O.D. at Williamston [161692], and it is probable that the sea at this period was prevented from extending into the Duffus area by ice.

North-east of Duffus the glacial sands and gravels form a stretch of ground with low relief about the 100-ft contour, though a few sandy mounds rise above the general level. A prominent mound south-east of the Easter Covesea was thought by Ogilvie (1923) to be a storm beach of the '80-ft' sea, but is more likely to be of glacial origin.

The distinction between deposits of glacial and marine origin is obscure in the neighbourhood of Gordonstoun. Clay similar to that of the post-Glacial beach rises to the 50-ft contour at one point and appears to pass under the sand and gravel ridge which extends north-north-west from St. Michael's Church [193689]. A glacio-lacustrine or marine origin for the clay appear equally likely, since the north-west-trending gravel ridge could have originated as a storm beach.

Two small areas of glacial sands flank the north margin of the Spynie alluvium, one at Saltershill, and the other from Balormie to Ardivot. Both have been bevelled at the 50-ft contour, probably by marine action. At Salterhill, the deposit appears to be mainly sand, 8 ft being seen in an excavation at one of the farm buildings. A section in the feature 600 yd S. of Balormie shows the following: fine-grained micaceous sand with beds of reddish silt 6 ft; reddish silt 2 ft; on interbedded fine-grained micaceous sand, reddish silty clay and silt 4 ft.

Just east of this in an old sandpit a little below 50 ft O.D., there are about 11 ft of reddish, micaceous sand with a few boulders. Micaceous silt is seen at the entrances to rabbit burrows at one or two points in the prominent cliff line of the former Loch Spynie, and further small exposures of sand, gravel, and clay can be seen south of Ardivot at and near the till section described on p. 92. These sediments differ from the late-Glacial marine clays of Lossiemouth Airfield, exposures of which can be seen below post-Glacial beach deposits in a roadside ditch 400 yd N. of Balormie.

On the south side of the Spynie alluvium, sand and gravel overlie the till and solid rock between Muir of Myreside and the Hill of Spynie. The deposits are undulating with ridges and small plateaux rising above 50 ft O.S., and show no obvious evidence of reworking by the late-Glacial sea. North of Myreside a number of kettle-holes are preserved at about 50 ft. O.D. An intermittently-worked sandpit 350 yd N. of Lochside exposes about 30 ft of almost horizontally bedded sand with gravel lenses about 2 ft thick near the top, and micaceous sand is exposed at a few points in the old cliff-line east of this point as far as the Elgin–Lossiemouth road. On the Hill of Spynie, sandy material forms the lower slopes, occurring as occasional mounds and small terraces, and the flat sandy area north of Pitgaveny House is probably underlain by glacial sands.

District between the Lossie and the Spey. Between the Lossie and the Spey, the various topographical forms taken by the meltwater deposits fall into two broad categories. South of a line from Dykeside [209589] to Lhanbryde and Sleepieshill Wood are spreads of fluvio-glacial outwash, and north of it are hummocks and plateaux of sand characteristic of the country south and east of Elgin. The fluvio-glacial deposits may be classified into (a) spreads of outwasb gravel in part associated with the Blackhills Overflow Channel, and (b) a dissected terrace which extends from Hillhead Wood (south of Birnie) to Lhanbryde, where it merges into the hummocky country to the north.

In the south-west, the sands of Castlehill [217578] and the higher sand and gravel country south-west of and east of Longmorn are isolated remnants belonging to (a), and farther east the relatively high flat of Stroan Hill [260590] is another.

Within the area covered by the one-inch map, the outwash deposits of (a) begin at the sheet boundary and descend generally from a height in excess of 250 ft near the point of debouchment of the Blackhills Channel to near the 200-ft contour 4 miles to the north-east. Near the point of debouchment, the outwash forms gently-sloping sand and gravel spreads, but north and east these merge into typical kettle-hole gravels. At several points, however, kame-like plateaux rise above the general level, and a height of 257 ft O.D. is recorded on one such feature west of Steelsbrae [310611]. The material for these and other spreads may have been derived partly from the nearby ice-front. At one point the sands are seen to overlie lacustrine clay associated with the Fochabers Glacial Lake (p. 105).

During and after the deposition of the gravels, the meltwaters following the course of the Burn of Blackhills (as indicated by several terrace features) flowed at the earlier stages to the east and north-east. Later, as the ice decayed, the waters turned north-west and west to erode through the earlier deposits into the boulder clay beneath, the flow possibly being partially sub-glacial. Exposures in gravel pits and in the Black Burn itself show that the higher deposits tend to be coarse boulder gravels, and fragments a foot or more io diameter are not unusual. In a gravel pit [27855930] East of Newton, the coarse boulder gravel has been stripped away to reveal finer-grained gravel resting on an assemblage of obliquely bedded gravel with intercalations of peat, in turn overlying sand. A composite section is as follows: boulder gravel, fragments up to 1 ft diameter 15 ft; sandy grit 2 ft; sandy, fine-grained gravel with included peat bands up to 3 in thick 3½ ft; on medium-grained, current-bedded, pale buff sand 2 ft. The peaty layers may bave been emplaced during the quarrying of the gravel.

The kettle-and-mound topography north-east of Loch na Bo is well seen from the Elgin–Fochabers road in the vicinity of Loch Oire [287607], and Loch na Bo itself evidently occupies a large kettle-hole.[1] Between Loch Oire and Wester Marchfield [297604] several roadside exposures show interbedded sand and coarse gravel, and in a sandpit [29656083] on the King's Road, 9 ft of lacustrine sand and reddish clay was recorded before obliteration by road works. East of Sleepieshill Wood, the moundy and plateau-like deposits, where seen in surface scrapings, consists of coarse-grained sand carrying boulders up to 2 ft across. The fluvio-glacial gravels terminate a short distance north of Hills [318618] where they are truncated by an extensive terrace of the River Spey. These more northerly spreads probably originated locally from reworking of moraine along a nearby ice-front.

The terrace (b) is best seen between Hillhead Wood [205578] and Longmorn Distillery, both within the area of Sheet 85. In a pit 400 yd SSW. of Dykeside [209588] micaceous sand about 15 ft thick with gritty horizons and scattered pebbles is exposed, and intermittent scrapings east of this point suggest that much of the terrace is built of similar material. Southwards, however, tbe terrace becomes more gravelly. Between Longmorn and Lhanbryde, the terrace is considerably dissected and the surface has declined from above the 200-ft contour near Hillhead Wood to 160 ft south of Lhanbryde. The sand composing the terrace has been worked at several points, and at Doo Hill, 150 yd ESE. of Coxton Tower [262607], a 30-ft deep sandpit shows the deposit to be almost free of gravel. The flat top of the terrace in the Longmorn–Hillhead stretch is transected by a number of channels which in a few cases, for example near Clackmarras [247585], are cut off at their downstream ends by later deposition of sand. These features suggest fluctuating erosion and deposition, perhaps related to changes io the nearby ice-front, and it is significant in this respect that kettle-holes occur in one channel north of Stroan Hill [260590]. To the south-east, on the ground of the adjoining

[1] Both Loch na Bo and Loch Oire are partly artificial, the latter having been excavated and the former having its level controlled by sluices.

Sheet 85, the terrace deposits slope gradually upwards south of Hillhead Wood towards Shougle [212552] and seem to be associated with the course of the River Lossie where it flows in an east-north-east direction from Dallas to its junction with the Leanoch Burn.

The terrace (b) described above is a distinctive feature south of Lhanbryde, but north and north-east of this village it merges into a tract of stratified drift with more uneven topography, transitional towards 'the dead-ice' terrain to the west. Several series of sandy outwash flats, varying in height from 120 ft near Urquhart to 90–100 ft near Nether Meft [272642] and Urquhart Station [287631] are interspersed with more moundy country, and remnants of higher fluvio-glacial spreads occur at Maryhill and Castle Hill [273634]. Elongate flat-bottomed depressions about the 50-ft level occur along the lower course of the Stripe Burn (which reaches the coast near Gladhill [323652], and south-south-west of Corbiewell [318653], and, in contrast, the Binn Hill forms a dominating feature rising well above the 200-ft contour. North of Waterscott [293653] kettle-holes occur at the 50-ft contour, but below this the deposits may have been modified by marine action. The following section was recorded during building excavations at Lhanbryde [27756100]: blown sand and soil 0–3 ft; clayey buff sand and pinkish buff clay 0–3 ft; on medium-grained pale buff current-bedded sand 9 ft +. At a large recently-worked pit [28206150] half a mile north-east of Lhanbryde, another composite section shows the variable nature of the deposits: pale silvery-buff silt to fine sand 8 ft; pale buff silt and reddish clay (lateral variation to silt and sand) 3–6 ft; sandy gravel, pebbles and cobbles up to 9 inches diameter 6 ft; on coarse, current-bedded, buff sand with pebbly intercalations 6 ft +. Farther north, sections are uncommon. At Wallfield [296653] and a little north-west of Waterscott, there are patches of lacustrine silt and clay, and thin bands of similar material can be seen on the other side of Binn Hill in the old sea-cliff at Gladhill. About 200 yd north of Corbiewell [318653], a recently abandoned sandpit shows 20 ft of yellow sand with a few pebbly intercalations and a discontinuous bed about a foot thick of silty clay near the top. The surface of the Binn Hill is sand or gravel with little or no soil.

The third element in the meltwater desposits of this subsection is the 'dead-ice' terrain which includes the area enclosed by Nether Birnie [207592], Bishopmill, Leuchars House [260647] and Lhanbryde. Here meltwaters from the south-west and south spread silty and sandy outwash deposits across and below the thinning ice. After the ablation of the ice, some of the sediments formed mounds resting on a highly irregular surface of boulder clay while others retained a plateau-form. The drainage, no longer channelled along an ice-front, filtered between the mounds in a series of south-east to north-west anastomosing channels. The original form of the deposits has been modified through erosion by the River Lossie, and, on the lower ground, by marine incursions, particularly during post-Glacial times.

Typical of the morphology and sedimentation are the deposits east of Duffus Hillock [214594]. Here some of the larger mounds have flat tops (probably depositional surfaces), whilst others (e.g. Birkenhill Wood to the north-east), which are of equal or greater height, do not. Between the major sand-mounds, the glacial sands are of negligible thickness and correspond with level surfaces which appear to be related to channels in the terrace farther south. One of the flat-topped deposits has been worked at a point near Duffus Hillock [21615963], where the following section is seen: sand with lenses and beds of silty clay 20 ft; interstratified sand, gravel and silty clay, gravel units being up to 4 ft thick with the fragments up to 9 inches in diameter 20 ft +.

Farther north, well-marked plateaux occur around the Elgin Golf Course [215610], and in one of these, north of the club house, the till appears to have been planed off before deposition of the sand took place. Between New Elgin and Lhanbryde mounds of sand lie on an irregular surface of boulder clay.

A well-marked sand plateau deposit can be seen north of Elgin. It commences as a terrace at the base of Quarry Wood Hill west of Sheriffmills and the back-feature at

100 ft O.D. can be traced around the hill into the suburbs of Bishopmill. The terrace itself continues in an east-south-easterly direction for another 2 miles. A remnant is enclosed in the U-shaped bend in the River Lossie west of Elgin. The top of the plateau is at approximately 100 ft O.D., but there are numerous subordinate steps of the order of 10–20 ft, and fragments of higher terraces between 120 and 150 ft O.D. occur at Linksfield [224640] and Lesmurdie. The gentle slope on the individual terraces is from south-east to north-west and north rather than along the length of the plateau, suggesting deposition by meltwater derived from the south or south-east. It seems to have been formed at a period later than the gravelly terrace on the south side of Quarry Wood a little farther west (p. 99). A fine section can be seen at a sandpit at Lesmurdie [22856358], where about 50 ft of current-bedded, pale buff micaceous sand with lenticles of gravel in the top two feet are exposed.

District east of the Spey. Apart from several isolated patches on the higher ground in the south-east corner of the district, the main areas of sand and gravel are disposed in two belts extending from north of Fochabers almost to Buckie. Plateau-forms are the exception, and the topography associated with the deposits varies from gently undulating to moundy.

A little east of Fochabers, at Boghead, there is a small area of fine-grained silty sand in part below the level of neighbouring stream gravels. The field relations suggest that the sand was buried by ice while the stream gravels were being deposited, and this view is supported by the occurrence of a kettle-hole in the latter. Between Ordiga and Bridge of Tynet there are numerous hillocks of sand, sometimes pebbly, and the association of these with mounds and ridges of till suggests a genetic link with stagnant ice (p. 96).

South and east of the moundy area between Bridge of Tynet and Wellhead [383603] there is a stretch of almost flat outwash (mainly fine-grained sand) sloping gently south-eastwards, and somewhat dissected by the Tynet Burn and its tributaries. The outwash appears to have been derived from ice which occupied the Ordiga neighbourhood during the Elgin Oscillation. On the other side of the Tynet Burn, a strip of sand extends eastwards to a point north of Drybridge. Bremner (1934), suggested that at one period the whole volume of meltwater flowing down the Spey Valley found its way around the northern slopes of Ordiquish and Whiteash Hills, but the fine-grained sandy nature of the deposits, their small extent, the direction of slope and the lack of marked erosional features, do not support this view. The fine-grained sands were probably deposited from waters originating in the Ordiga ice-field.

A narrow strip of gravel and pebbly sand, cut into by the uppermost Spey terrace, runs from a mile south-west of Auchenhalrig [370619] to the mouth of the Tynet Burn. It is probably of no great thickness, since hillocks of till rise above it at several points, and at the mouth of the Tynet Burn the exposures are capped by only 3 to 5 ft of sand and gravel.

From the Tynet Burn to Buckie, a tract of country about half a mile wide is underlain by sand and gravel. In a sandpit 200 yd WNW. of Mains of Tannochy [386637], some 25 ft of off-white sand with current-bedding are exposed in a marked sand mound, and a similar thickness of more pebbly sand in a quarry on the right bank of the Gollachy Burn above the old sea-cliff. At the top of the old sea-cliff on the north side of Buckie Golf Course, a pit in a sand mound exposed 20 ft of cross-bedded sand [41186506].

The Spey Valley. The well-marked gravel terraces which are a feature of the lower Spey extend southwards as far as Orton, and the time of their formation covers the whole period between the retreat of the last glacier ice and the present day. Their importance in the late-Glacial history of the region is that to some extent they form a link between the ice-retreat stages on the one hand, and the fluctuations in sea-level on the other. Two main sets of terraces occur (Fig. 17): the great Mosstodloch Terrace, which extends from Orton to Stynie, and the higher terraces south of Mosstodloch are certainly late-Glacial, whilst the lower terraces, which rise only a few feet above the modern floodplain, are considered to be post-Glacial in age. A terrace remnant between Lower Stynie [337612] and Lunan Wood, the Lunan Wood Terrace, is less easily classifiable, but may be late-Glacial in age.

Before discussing the Spey terraces in detail some attention must be given to the deposits which underlie the gravels south of Fochabers. Sections in the Red Burn, south of Balnacoul Wood (detailed on p. 94) show laminated clay overlying an apparently level surface of boulder clay at about 220 ft O.D. In one of these sections, the clay is overlain by outwash sand of the Elgin Oscillation. At Orbliston, on the south side of the Red Burn, a recent excavation proved similar laminated clays to rest on till, and to be overlain by the fluviatile gravels of the Orbliston Terrace, the highest of the river terraces in the lower Spey valley. The height of the laminated clays (which are in part varved) is here 212 ft O.D. Lacustrine deposits were formerly seen below lower terraces (Trochelhill Terrace and Balnacoul Wood Terrace, Fig. 17), near Inchberry (Hinxman and Grant Wilson 1902, p. 73), and at a point 400 yd NW. of Crofts of Dipple [324590]. On the east bank of the Spey at about 220 ft O.D. laminated silts and clays up to 5 ft thick crop out between the till and the overlying sand and gravel of the Ordiquish Terrace on the north bank of the Aultderg Burn, and about a mile to the north is situated the section with varved clay detailed in Fig. 16, p. 95.

From the sections given above, there is ample evidence that before the deposition of the Spey terraces this part of the Spey valley was occupied by a lake, here termed the Fochabers Glacial Lake. If the varves in the section illustrated in Fig. 16 are annual, then this part of the sequence alone must have taken several hundred years to accumulate. The Ordiquish Terrace at 240–250 ft on the east bank of the Spey appears to mark part of the lake shore. Since the Orbliston Terrace reaches a height of 240 ft O.D. and there is no evidence of contemporary ice in this part of the Spey valley it follows that the lacustrine deposits must have filled the valley to at least this depth.

The highest fluvio-glacial terraces of the Spey valley are the Orbliston Terrace, the Trochelhill Terrace, and the Balnacoul Wood Terrace, of which only the Balnacoul Wood Terrace and a small part of the Trochelhill Terrace come within the bounds of the Elgin District (Fig. 17). North of Orbliston, the Orbliston Terrace is cut into moundy sand deposited at the limit of the Elgin Oscillation. Both the Trochelhill and Balnacoul Wood terraces merge into kettled gravels in part association with Blackhills outwash, and were formed when an apron of gravel-covered ice was standing a short distance to the north-west.

The most extensive of the terraces is the Mosstodloch Terrace which can be traced for four miles from Orton to the Muir of Stynie near New Mains, and reaches a width of a mile at Mosstodloch. The slope is 16 ft per mile (much the same as that of the present alluvium) over most of the terrace. A small stretch where the gradient increases to 30 ft per mile not far north of the Red Burn delineates part of an alluvial fan of that stream. From the Muir of Stynie northwards, undulations and traces of kettle-holes appear in the terrace, and at New Mains [326624] it merges into low mounds of glacial sand and gravel. On the east bank of the Spey, the probable equivalent of the Mosstodloch Terrace is seen at Lions Den [357610], where the height ranges between 95 and 100 ft, and it is carried by a narrow intermittent feature at a slope of 11 ft per mile to below 75 ft O.D. north-east of Upper Dallachy where it merges into glacial gravels. At its northern end the terrace has been partly truncated by marine action at the 50-ft level (Fig. 17). At Fochabers, remnants may occur on the west bank of the Fochabers Burn, but most of the village is built on a gravel fan which slopes down to a level below that of the Mosstodloch Terrace. These fan gravels were probably in contact with ice on the east side, where kettle-holes are preserved.

From the foregoing it is clear that the Mosstodloch Terrace is not a simple feature. During its formation it is likely that ice still covered the ground north-west of the Muir of Stynie, and the supposed equivalent of the terrace on the east bank of the

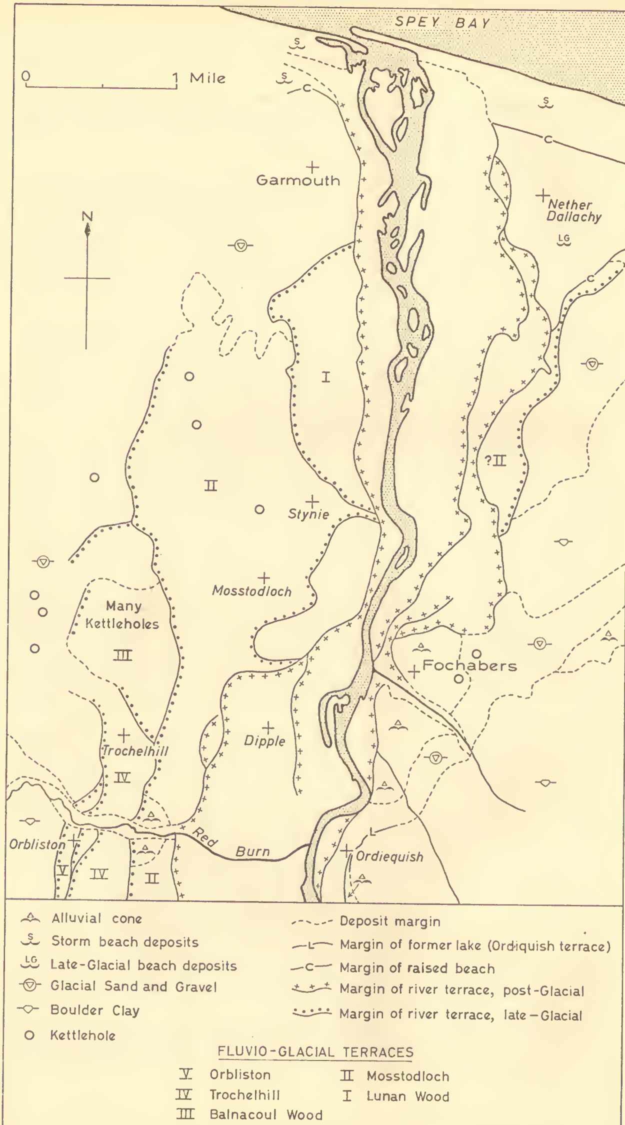

FIG. 17. *Sketch map of Spey terraces*

Spey may also have been in contact at a few points with glacier ice. At this stage the lower sandy terrace (b) (Table IV, p. 120) of the Blackhills outwash was being laid down, and the sea had already receded from its highest late-Glacial level.

The Lunan Wood Terrace falls from above 80 ft O.D. at Lower Stynie to just below 60 ft at its northern extremity, with a slope of 16 ft per mile. Projection of the slope seawards to the height of the post-Glacial beach (20 to 30 ft O.D.) takes it well north of Garmouth, and there is, therefore, little doubt that it is an earlier feature. The projected slope falls to 50 ft O.D. just north of the railway viaduct, and allowing for a north-easterly course of the former river, and the known occurrence of a strip of late-Glacial beach at about 50 ft O.D. at Dallachy, it is likely that the terrace was formed when the sea was at this level.

The recent alluvial terraces of the River Spey are deeply incised into the earlier late-Glacial series, and in places the river has cut through boulder clay into solid rock. Most of the alluvium is gravel, though silt is deposited in backwaters. The gradient is a constant 16 ft per mile from near the mouth to well south of Fochabers, and in many parts the flood-plain and older terraces are over a mile wide. A feature of the River Spey is that near the mouth it becomes braided, though upstream it is characterized by meanders. It may thus be on the borderline between a higher and a lower flow regime (Leopold and Wolman 1957; Allen 1965). One low terrace about 5 ft above the flood-plain can be traced from near the river mouth to the Dipple area, and traces of a higher terrace occur at Gordon Castle and due west of Dipple itself. The latter may have been formed at some stage during the post-Glacial rise in sea-level, since it is 15 to 20 ft above the flood-plain.

RAISED BEACHES

Raised littoral and sub-littoral deposits accompanied by features of marine erosion have been mapped at many localities below 100 ft O.D. The heights of the back features of the raised beaches have been determined at a number of localities by means of a quickset level, with traverses closing on Ordnance Survey bench-marks. The earlier beaches, which were contemporaneous with the last stages of the Pleistocene ice-sheets and which range in height from 85 ft to below 50 ft O.D., are in places truncated by a later post-Glacial series which reaches a maximum height of about 30 ft O.D. Evidence from elsewbere in Scotland, for example the Forth valley and the Aberdeen[1] area suggests tbat a considerable time interval separates the two groups, during which the sea-level fell well below the present Ordance Datum and the climate favoured the growth of extensive forests, the remains of which are preserved as the so-called Boreal Peat. It is probable that the submerged forest peat exposed at low tide in Burghead Bay belongs to this intermediate episode, but nowhere in tbe present area is the relationship of the peat to the raised beaches seen with any certainty.

LATE-GLACIAL BEACHES

On tbe east side of the Spey between Upper Dallachy and Lower Auchenreatb [373638], tbere is a well-marked feature at 46 ft O.D. incised into sandy till for most of its length. The accompanying beach platform has been much disturbed by airfield construction works, but the deposit on it is probably gravel. No other fragments of this beach can be seen in the Spey valley, but it may merge into the Lunan Wood Terrace (p. 107).

[1] See Jamieson (1865, p. 194) for tbe relations of peat and raised beaches in Aberdeenshire.

In the stretcb of country between Garmouth and Lossiemouth there is no certain evidence for the presence of raised beaches above 30 ft. At Winnyhaugh [336651] and south of Gladbill [323653], tbere are flats at about 45 and 50 ft O.D. respectively, but the former is a boulder clay tract, and the latter appears to be associated with fluvio-glacial or later fluviatile deposition. Near Nether Unthank [299663], there are doubtful traces of a feature at 70 to 80 ft O.D. as mentioned by Ogilvie (1923, p. 404) and west of Broomhill [295657] the relief of the ground below 50 ft O.D. is subdued. The occurrence of kettle-holes at and above the 50-ft level in this area is significant, giving an upper limit to marine processes.

Deposits and features of the late-Glacial marine incursion are well-developed near Lossiemouth, the sandstone and till 'island' of Lossiemouth being lapped around by beach deposits below the 80-ft contour. On the west side of the hill, beach features are seen at 74 ft, 64 ft and 48 ft O.D. and the new housing estates are partly built on beacb gravels deposited while the sea was at tbe highest of these levels. The boulders in the beach deposits are largely of the local Triassic sandstone.

The ground south of a line from Lossiemouth to Covesea is a complex of late- and post-Glacial beach deposits. West of the lighthouse and also some distance north-east of Easter Covesea [193707] are stretches of beach with a back feature at just over 70 ft O.D. Traces of a still higher beach (possibly 80 ft O.D.) are visible 400 yd ENE. of Easter Covesea. Due east of Easter Covesea is an extensive area of sandy, pebbly beach ridges with hummocks of blown sand which extends southwards from a back feature between 59 and 65 ft O.D.[1] From borehole evidence the pebbly sand is known to overlie the sparsely foraminiferal clays whicb underlie parts of Lossiemouth Airfield.

The superficial deposits encountered during the drilling of the Geological Survey Borehole on Lossiemouth Airfield [21586986] are summarized below:

	Thickness Ft	in
5. Sandy soil	1	6
4. Micaceous sand with horizons of silt and clay, shell fragments	5	6
3. Olive-grey, silty clay with a few sandy horizons	20	0
2. Olive-grey, silty, pebbly clay, merging into yellowish sandy till	11	6
1. Dark grey till composed dominantly of shale fragments	3	6

In this succession bed 4 is probably of post-Glacial age. Bed 3 can be equated with the foraminiferal silty clay mentioned in the preceding paragraph and is likewise taken to be late-Glacial in age. Faunal lists are given on p. 138.

On the south side of the Locb Spynie trough late-Glacial marine deposits are absent, and there is little evidence of beach-features above 30 ft O.D. even at points not protected by the Roseisle–Covesea ridge. This negative evidence, added to the occurrence of kettle-holes below 80 ft O.D., gives support to the hypothesis that this ground was covered by land ice while tbe late-Glacial sea stood at its highest levels. Since there are contemporaneous marine deposits only a little to the north, the ice front must have extended temporarily from

[1] The feature seems to slope gently seawards, suggesting that it could possibly be partly of fluvio-glacial origin.

Covesea south-eastwards to the Ardivot area, and then east and north-eastwards to the open sea near Speyslaw [285668].

Between Covesea and Burghead there are a few remnants of late-Glacial beaches. East of Hopeman is a sandy flat near 80 ft O.D. and a few feet of shingle at this height can be seen just west of Hopeman Lodge and in the north-east part of the village where they are associated with a feature at about 78 ft O.D. Just north of Hopeman Lodge there are traces of a lower beach at 65 ft O.D., which can also be seen west of Hopeman. A section of the 65-ft beach at Greenbrae Quarry shows several feet of shingle banked against till and resting on a striated glacial pavement.

Beach features up to about 90 ft O.D. can be followed around the west end of Clarkly Hill, but the exact heights are uncertain because of extensive blown sand. Possibly both an '80 ft' feature and one about 70 ft are present. South of Burghead, there is an extensive area of late-Glacial beach below blown sand, and exposures of gravel at about 50 ft O.D. are visible in a railway cutting about 1200 yd S. of Burghead railway station. These gravels have lower indices of sphericity and roundness than the neighbouring post-Glacial storm beach shingle, and are probably reworked glacial gravels transported a short distance in the long-shore drift. At Burghead itself the cliff north of the harbour is surmounted by thin bouldery gravel which yields rolled shell fragments (Wallace 1883, p. 49). The top of the gravel below the rampart of the old fort is above 40 ft O.D.

South of the Roseisle–Covesea ridge late-Glacial beach deposits and features are not present, and, with the possible exception of the clays mentioned on p. 101, the only evidence of marine action during this period is the smooth topography below about 50 ft O.D. The undulating country between Spindle Muir and Coltfield, formed of glacial sand and gravel, contrasts sharply with the flat shingle deposit at 50 ft O.D. which occurs about a mile north-west of Coltfield. This latter, dissected by post-Glacial marine action, may have been an off-shore bar, though Ogilvie (1923, p. 308) prefers to class it as a storm beach.

East of Forres (which is just beyond the west margin of the area of Sheet 95) a somewhat embayed feature, which falls from 75 ft O.D. in the west to 66 ft farther east, is thought to be a fluvio-glacial terrace margin, and it is only at lower levels that features appear to be connected with or modified by marine action. At the west margin of the area of the sheet there is an intermittent feature at about 50 ft O.D. which falls to 47–58 ft near Grange Hall [064606] and Newton of Struthers. What is probably the same break of slope is again seen at a height of 44–46 ft O.D. by Milton Brodie House [092629] as far as Easter Coltfield. A short stretch of terrace margin at 36–37 ft can be seen at Newton of Struthers [084613]. The higher of these two beach margins thus slopes very gently from west to east (cf. Sissons 1963), suggesting that the remnants of the late-glacial beaches elsewhere in the district are tilted in the same direction.

POST-GLACIAL BEACHES

Within the area covered by Elgin (95) Sheet it is often difficult to distinguish with certainty between the features and deposits of the post-Glacial maximum sea-level and those of more recent times. This is particularly so in some areas of storm beach gravels where deposition has probably been continuous throughout. The height of the beach-feature is affected by factors such as the type of material involved, the degree of exposure, and whether the main process is one of erosion or of deposition. Thus in the Loch Spynie area erosional features in drift occur as high as 30 ft O.D., but on the open coast between Burghead and Lossiemouth where there is solid rock, the old cliff line is more nearly at 20 ft O.D. The storm beach shingle ridges exceed 30 ft O.D. in places. There is some evidence of an intermediate raised beach at 15 to 20 ft O.D., but this is clearly seen at few localities. Another factor which is difficult to assess is the possible effect of differential isostatic uplift, thought to have tilted the post-Glacial beaches in the Forth valley (Sissons 1963), but if this has indeed taken place in the Elgin area it has been masked by the other variable factors. In the following account the post-Glacial beaches (including the modern beach) are described together, beginning with a description of the coastal areas. A summary of the chronology of the post-Glacial beaches is given below (p. 114).

DETAILS

District East of the Spey. A well-developed, but narrow stretch of low raised beach is present between Portessie and Portgordon, east of the Spey. The beacb platform, which appears to be rock partly covered by thin gravel, is at a height of 16 to 25 ft, and is backed by a well-marked cliff, the base of which is at about 20 ft O.D.

From Porttannachy westwards the character of the coast changes with the appearance of the shingle storm beaches which extend nearly to Lossiemouth. Just west of Porttannachy the storm beach is slightly modified by an alluvial spread brought down by the Tynet Burn, but from here to Spey Bay about 9 storm beach-ridges form a belt 600 yd wide. The height of the ridges is just above 20 ft O.D.

A short distance east of Lower Auchenreath [373638], there is a small patch of raised beach with a back-feature at 28 ft O.D., and a much larger shingle platform at 26 to 29 ft O.D. at Nether Dallachy [360640] is also backed by a feature just below 30 ft O.D. west of Lower Aucbenreath. South of this latter point the beach-feature has been obliterated by constructional works. A storm beach-ridge probably associated with the feature at about 30 ft starts just north of Lower Auchenreath and is gradually truncated westwards by the lower storm beach described in the preceding paragraph.

Garmouth to Lossiemouth. From the mouth of the Spey westwards to Nether Unthank [299663], the coast is backed by a belt of storm beach-ridges some 800 to 900 yd deep. These run parallel to a feature which lies at about 25 ft O.D. along the face of the Binn Hill but which descends gradually eastwards to 22 ft near Winnyhaugh [336651]. Kingston is built on shingle, part of which must bave accumulated wbile the Spey passed westwards over the low alluvial flat to the south, and the curved ends of the bars can be seen west of the village beside the extensive gravel workings. From a consideration of tbe heights of the shingle ridges, the back-feature, and the alluvial flat, it is tbought that a minimum width of 600 yd of shingle has accumulated at a sea-level at and up to 5 ft above present sea-level, and the remainder at mean sea-levels up to 15 ft O.D.

That the tidal drift which is responsible for tbe shiogle ridges is still active is shown by the continuous tendency for a shingle spit to grow across the mouth of the Spey from Tugnet, diverting the river westwards to threaten the village of Kingston. New artificial outlets for the Spey are trenched through the ever-growing spit from time to time (Grove 1955), the latest straightening having been carried out in the latter half of 1962.

The materials forming the shingle ridges are of heterogeneous origin. The most frequent pebbles (about 70 per cent) are of Moine granulite and quartzite. Vein quartz, feldspar-porphyry and sandstone of Old Red Sandstone age are common, and there are small quantities of various granites, pegmatite, diorites, basic igneous rocks, Old Red Sandstone conglomerate, breccia and cornstone, Triassic sandstone, slate, pelitic schist and hard Jurassic shale.

Westwards from a point 700 yd W. of Nether Unthank, the storm beach-ridges are no longer associated with a back-feature and expand from about 800 yd to over a mile across near the River Lossie, where the southward-curving ends of the bars end abruptly against the river alluvium. The more southerly ridges are between 25 and 30 ft O.D. with intervening sandy flats at 16 to 18 ft O.D. and there is a sharp or gradual descent to a lower series of flats and ridges at 13 to 21 ft O.D., which are a continuation of the storm ridges near Kingston. The modern storm beach ridge is 17 ft O.D. These younger ridges yield many rolled shell fragments. At the time of surveying, a new shingle ridge was gradually being extended westwards and had advanced some 500 yd from its 1958 position to a point at grid reference 26616858 in 1962. Ahead of the new ridge, coastal erosion was evident. The higher shingle ridges probably formed at a mean sea-level about 15 ft O.D., assuming that specific marine processes, such as the long-shore drift, were the same then as now.

South of the storm beaches there are several small areas of raised marine or beach deposits rising above the Loch of Cotts and the Lossie alluvium, east of the river, e.g. at Speyslaw [284668]. A long low mound on Milltown Airfield is possibly a deposit of glacial sand much reworked. Patches of gravel at Inchbroom [254668] and Blacklays [252661] may at one time have been connected with the storm beaches to the north.

From Caysbriggs [250670] to Lossiemouth the storm beach gravels are similar to those farther east, but the lower, shell-bearing ridges are confined to a strip 100 yd across. Fine temporary sections are exposed in gravel-workings south of Lossiemouth where over 20 ft of bedded shingle and sand can be seen (Plate IV). The bedding dips in a northerly direction, at right angles to the trend of the beach ridges, and the top 6 ft or so of gravel is blackened by organic matter and hardpan. Just north of Caysbriggs, the beach gravels carry little vegetation, and the storm ridges are well preserved.

Lossiemouth and Drainie. A further stretch of beach gravels is preserved between Lossiemouth and Covesea Skerries Lighthouse. The old harbour at Stotfield is backed by a cliff of siliceous Triassic sandstone which overlooks the golf course, and a similar cliff in Hopeman sandstone can be traced for a short distance south of the Covesea Skerries Lighthouse. The base of both cliffs is 18 to 20 ft O.D. though built up higher by blown sand at many points. Near the coast the beach deposits of Stotfield Links, in which few traces of storm ridges can be seen, rest on skerries similar to those just offshore, and are separated from the extensive post-Glacial marine flats on the airfield to the south by a high storm ridge (30 ft O.D.) which carries part of the Lossiemouth–Covesea road. This storm ridge belongs to an earlier episode of storm beach formation, and like the gravels south of Lossiemouth contains very few shell fragments.

Much of Lossiemouth Airfield is underlain by post-Glacial beach deposits thinly spread over late-Glacial marine clays. A section formerly exposed at a point 800 yd ESE. of North Greens showed up to 10 ft of sand and gravel with partially decomposed shells. From Kinnedar southwards to Muirton [225682] there is much shingle, probably the remains of a storm beach destroyed by cultivation, and a pit dug by the Soil Survey at a point 250 yd S. of Kinnedar showed the following section: soil 10 in; gravelly sand 2 ft 8 in; sand 1 ft 2 in; on fine-grained silty clay with plant remains 1 ft 2 in. The plant remains may be the same age as the Boreal Peat, and the clay is probably part of the late-Glacial sequence encountered on Lossiemouth Airfield. The storm beach south of Kinnedar was probably thrown up on to the edge of eroded late-Glacial clays before protection was afforded to the coastline by the growth of the storm beach-ridges south-east of Lossiemouth.

At Ardivot, less than a mile south of Muirton, a beach feature at 20 to 25 ft O.D. is cut into sand and gravel, and the sandy platform fronting it, though eroded on its southern side, grades north-eastwards almost imperceptibly into an arm of the Loch Spynie flat.

Covesea to Burghead. East of Covesea an embayment preserves a fine stretch of raised beach cliff with incipient stacks. The height of the back-feature is 17 to 21 ft O.D. and the shingly platform in front, partially covered by blown sand, is about 14 ft O.D. West of this point the high ground is fronted by the modern cliff-line almost to Hopeman, though the presence of small embayments and a number of caves not now reached by the sea suggest that the cliff is of composite age. The Gipsies Cave [160702], eroded along a small fault, was mainly excavated at a sea-level higher than at present, as was the cave called 'Sir Roberts Stables' [182707]. At Hopeman a narrow strip of low raised beach much obscured by blown sand, can be seen, backed by a cliff based at 15 to 20 ft O.D., and at Cummingstown the composite nature of the cliff-line is shown by the occurrence of a number of caves formed at present and higher sea-levels. The harbour area of Burghead, once an island, is connected by a storm beach (maximum height 36 ft O.D.) to the mainland at Clarkly Hill.

Burghead to Kinloss. The ground bordering Burghead Bay was mapped in considerable detail by Ogilvie (1923) and by Steers (1937). Much of the topography is now partially obscured by forestry development and an appreciation of the beach deposits is further hindered by spreads of blown sand. On a broad scale, however, the coastal morphology falls into two distinct sections, (a) a belt of shingle ridges more or less parallel to the coast, and (b) strips of alluvium inside the shingle ridges backed in a few places by a feature between 20 and 25 ft O.D. These grade into peaty flats between 20 and 30 ft O.D. which occupy depressions in the glacial deposits. North of the College of Roseisle a sandy flat connects one of the alluvial strips with the post-Glacial beaches in the Loch Spynie depression.

The tract of shingle ridges, which was mapped in detail by Balchin before extensive tree-planting (see Steers 1937), ranges in width from 200 yd to over a mile. It is interrupted along the line of the Millie Burn (which reaches the sea at grid reference point 107665) and again near the Bessie Burn [097653] by sand-filled hollows. The Millie Burn evidently drained the former Loch of Roseisle, and the sandy hollow near its mouth was occupied by a lake or lagoon in the 17th century (see the map by Gordon of Strathloch, 1640).

The coastal feature between Burghead and a point south of the Millie Burn is eroded into blown sand, but storm beach shingle, mainly hidden by sand but evidently contiguous with that at Burghead, laps around the late-Glacial beach deposit mentioned on p. 109. Bare shingle ridges exposed north of the mouth of the Bessie Burn are the remnants of hooked storm beach-ridges now largely eroded; they reach a height of about 20 ft above mean sea-level, and a section 750 yd NE. of the outlet of the Bessie Burn shows 12 ft of shelly shingle and sand. Inland from this point is a remnant of a late-Glacial beach at 50 ft O.D. truncated on the seaward side by a well-marked feature at 25 ft. The sandy and shingly flat below the feature can be traced south-westwards and isolates a series of storm ridges west of Muirhead [086631] from the main coastal series to the north. This isolated group of ridges was probably formed at an early stage and may be contemporary with some of the higher and older ridges near Lossiemouth.

From a point north of Muirhead to the western edge of the map, considerable changes have occurred in the distribution of dune sand since 1937, and many of the storm ridges described by Steers are no longer visible. The maximum height of those still seen is about 29 ft O.D. and it is significant in this connexion that this part of the coast is open to a longer 'fetch' than the stretch immediately south of Burghead. The whole coastline here is currently undergoing erosion, and the wartime coastal defences are slipping down to the modern beach. Sections of the raised beach deposits show bedded sand and shingle, frequently shelly, and peat with tree stumps covered by blown sand occurs in some of the hollows between the wasting shingle.

Behind the tract of shingle ridges an alluvial flat extends from Roseisle to near Lower Hempriggs, and another from south of Standingstone [136644] to Kinloss. North of the College of Roseisle, there is a flat expanse of sand, commonly 3 to 4 ft thick, overlying olive grey, silty clay. A thickness of peat at the junction of the two deposits may indicate the site of the former Loch of Roseisle. For about a mile and a half west and south-west of the College of Roseisle, the clay merges into coarse-grained, micaceous sand, but half a mile NE. of Lower Hempriggs [104642], it grades back into silty clay. This alluvial spread ends north of Lower Hempriggs where a thin peat overlies sand. The second alluvial spread is formed of sand in its eastern part, and is overlain by a large expanse of peat south of Upper Hempriggs [103636]. On both sides of Grange Hill [095625] are deposits of grey-brown and yellow-brown silty clay probably representing former tidal flats, but farther west near Kinloss these materials grade into gritty sands.

Loch Spynie depression to Loch of Cotts. In the Loch Spynie area, the rise of the post-Glacial sea inundated an already complex area of modified glacial, glacio-marine and glacio-lacustrine deposits. Features between 12 and 30 ft above mean sea-level are present, particularly in the Loch Spynie area, and in places well-marked features and cliffs at 5 to 10 ft O.D. have been left on the withdrawal of the sea during the last few centuries.

On the north side of the Loch Spynie depression from a point south of Duffus a feature at about 30 ft O.D. can be traced intermittently eastwards to Silverhills [208681] with traces of subsidiary features at 15 and 25 ft near Westerfolds. The beach flat in front of the feature is nearly a mile across in places and is for the most part on clay with some fine sand. To what extent the clay and sand are reworked glacio-lacustrine and late-Glacial marine clays is uncertain. A small patch of the higher post-Glacial beach with a back-feature about 25 ft O.D. occurs at Salterhill [205674]. The feature associated with the low Spynie alluvium is absent or poorly developed as far east as Westerfolds, from which place a prominent feature or cliff can be traced to a point east of Ardivot.

South of the Spynie alluvium, a feature at 12 to 15 ft O.D. is eroded into glacio-lacustrine clay at Kintrae [176655], and a narrow sandy beach backed by a feature at about 25 ft O.D. is present at Findrassie. The more recent beach-feature (at 8 ft O.D.) can be traced from Kintrae to a point just east of the present Loch of Spynie. Between Spynie and Pitgaveny House there is a further patch of the '25-ft' beach with a well-marked back-feature, and north of Scarffbanks [238663] storm beach-ridges are associated with a poorly defined back-feature at about 30 ft. The last trace of this upper post-Glacial beach on the west side of the River Lossie can be seen at Pitairlie [247654].

The alluvial flat of Loch Spynie extends from a point west of Waterton Bridge to the present Loch of Spynie. East of the silty alluvium brought down by the River Lossie, the low marine alluvial flat is continued to Innes House [278650] where it terminates in a marked feature.

In the Spynie district brown to grey, silty clay predominates at the surface around the margin of the alluvium, and is overlain eastwards and towards the centre by inter-bedded sands, silts and clays. Overlying these, probably marine deposits, are thin intermittent spreads of shell marl, basin peat, and fluviatile silt. Marine shells are occasionally ploughed up in the fields between Waterton [183662] and the Elgin–Lossiemouth road. At the old Morayshire Brick and Tile Works 300 yd ESE. of Gilston, the following section was recorded by Linn during the primary survey: soil 1 ft; sand 8 in; marine shells, mixed with pieces of wood 3 in; freshwater marl, thin peat above, 1 ft 2 in on fine-grained clay with occasional patches of sand 12 ft+.

According to the workmen, the clay extended a farther 30 ft in depth. At another point in the pit, the marine shell layer also contained freshwater shells and fragments of peat, and can probably be referred to events associated with the great Moray flood of 1829 (Lander 1830). A similar section was noted in the Geological Survey borehole at East Mains (p. 132), for which the faunal list is given on p. 138. Comminuted marine shells overlying peat and marl occur just below the surface in the field south of Gilston. On the north side of the present Loch of Spynie, at a point 800 yd due E. of Ardivot a section, not now visible, was as follows (Eyles and Anderson, 1946): fine yellow sand 18 ft; shell bed 1 ft; peat 1 ft 8 in; light blue clay 1 ft 6 in; dark clay 20 ft on clay and tbin sand beds 28 ft+.

Except for the great thickness of sand, which is the deposit associated with the feature at 20 ft O.D. east of Ardivot, this section compares directly with that at Gilston and suggests the possibility that some of the peat may pre-date the post-Glacial beach and be of Boreal age.

Much of the Loch of Cotts area is underlain by micaceous sand, with patches of peat and blown sand on top. At a point 250 yd E. of Lochside [268671], a section in the bank of a small reservoir showed the following: grey and yellow sand and soil 3 ft; grit and pebbles 2 in on greyish red (10 R 4/2) to olive-grey clay with silty laminae 4 ft+. It is possible that the clay underlies the sand over most of the low alluvium of the Loch of Cotts.

Post-Glacial Chronology of the Spynie Area

The following account inevitably owes much to the work of Ogilvie (1923) but differs in interpretation at a numher of points, notably in the height ascribed to the sea at the various stages.

On the rise of the post-Glacial sea, the River Lossie debouched into a wide bay, the southern and eastern shores of wbich were formed of glacial sands and the western shores of late-Glacial clays and sands, swamped at high tide. Being open to the sea, the bay at first suffered rapid erosion, and at this stage the shingle banks south of Kinneddar and the storm beacbes near Pitgaveny and Scarffbanks were built up (Fig. 18, Stage 1). At this early stage the sea reached its maximum mean height, probably near 18 ft O.D. However, erosion of the glacial deposits provided material for the extension of shingle beaches westwards from the Binn Hill and westwards from Lossiemouth. The remains of these ridges (Stage 2) suggest that the Binn Hill then extended farther north, erosion having continued until relatively recently. The River Lossie (or rather the drainage from the lagoon south of tbe shingle ridges) was constrained to flow through the gap 'A' (Fig. 18) at Lossiemouth. As suggested on p. 112 the earliest shingle ridges south of Burghead may have been formed about this time. The Stage 3 shingle ridges probably began to form when erosion had further truncated the Binn Hill and are thus formed partly from fresh glacial material and from reworking of earlier storm beaches. The ridges became attached to the high ground at Lossiemouth, diverting tbe drainage from the lagoon westwards past Roseisle into Burghead Bay. It may be tbat the waters of the lagoon became brackish or even fresb. Ogilvie (1923) suggested that the River Lossie might have broken through to the sea north of Kinneddar at point 'B' (Fig. 18) at this stage, but if this is so it has left no positive evidence bebind.

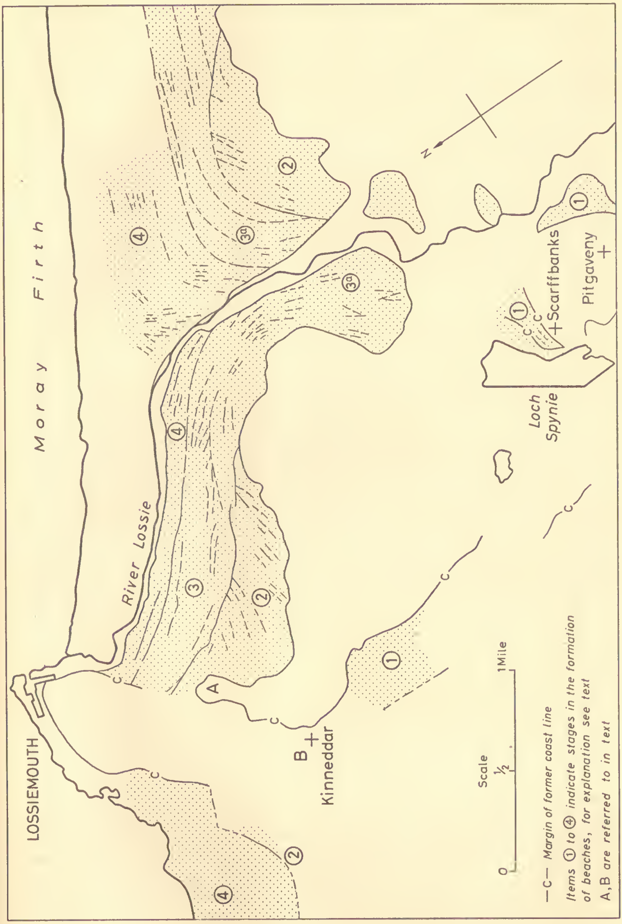

FIG. 18. *Map showing chronology of shingle beaches near Lossiemouth*

The next stage, still at a high sea-level (mean sea-level about 15 ft O.D.) was the breaching of the Stage 3 shingle by the River Lossie and the subsequent formation of the southward-curving ridges of Stage 3a. The opening of this gap would lead to the abandonment of the Roseisle outlet which thereafter became silted up. The closing of the Roseisle outlet probably occurred while the remaining shingle ridges soutb of Burghead were forming.

Though the sea-level may bave fallen slightly between stages 1 and 3a, a more definite fall now took place, possibly with temporary halts, allowing the cutting of the '20-ft' and '15-ft' features surrounding the Spynie alluvium. It is difficult to relate any of the storm beach deposits to this transitional episode (during which sea-level fell by nearly 10 ft) since the Stage 4 ridges appear to have been formed near or only sligbtly above those developing at present sea-level. The building of the Stage 4 ridges protected the Binn Hill from further marine attack and by further constricting the outflow from the lagoon probably assisted the relatively recent exclusion of the sea from Locb Spynie. Tbe supply of shingle now appears to be insufficient to carry storm beaches as far as Lossiemouth, and it may be tbis factor which is assisting erosion of the coast south of Burghead rather than changes in the pattern of waves and tides.

The changes in the Locb of Spynie during bistorical times have been recorded in considerable detail by several authors (Young 1871, Shaw 1882, Lander 1830) and only a brief account is needed here. Of the period up to the 14th century, there is little known excepting the tradition that in the 11th century tbe Danes built ships at Roseisle and that the strait south of Roseisle was then open to the sea. The evidence given on preceding pages suggests that the latter is unlikely, tbough it should be borne in mind that tbere may well have been large expanses of lake and marsh separating Roseisle from the higber ground to the south and there is also the possibility that a much older tradition may be preserved. It is certain, however, that there was a sea-port beside the Palace of Spynie until late in the 15th century, when silting of the Lossie reduced and eventually excluded the tide from the loch. This process was probably helped by the development of the Stage 4 storm beach mentioned above. Many of tbe marine shells seen in canals draining the Spynie alluvium probably date from this period, rather than from the marine incursion which took place in 1829, since Forsyth (1806) noticed oyster shells in the old bed of the loch at an earlier date.

On the exclusion of the sea many attempts were made with varying success to keep the River Lossie out of the loch and to obtain tbe impounded water. However, as late as 1783 Kinnaird's map (*in* Mackintosh 1928) showed that once again the loch extended its full length from Kintrae in the west almost to the River Lossie. It is of interest that a number of the 'holms' or islets which studded the loch north of Findrassie can still be picked out as low rises (marked as undifferentiated alluvium on the one-inch map) in the otherwise flat agricultural land. The successful draining of the Loch of Cotts in 1800 encouraged tbe building of the Spynie Canal between 1808 and 1812, but reclamation of the land received a set-back in 1829 when tbe catastrophic Moray flood broke up the embankments and sluices and the sea again entered the loch through the new canal. In 1880 a final and so far successful attempt was made at drainage, and all that now remains of the loch is a small stretch of water and marsb north of the old port of Spynie.

Freshwater Alluvium, Peat, and Blown Sand

FRESHWATER ALLUVIUM

Large spreads of alluvium of fluviatile origin are confined to the valley of the River Lossie and to that of the River Spey (described on p. 105). From Birnie northwards, the River Lossie leaves a confined valley and flows over a broad shallow gravel fan, the slope of which decreases from about 55 ft per mile to 18 ft per mile near the confluence with the Black Burn. The fan, which is lower at its margins than the present largely artificial course of the river, was probably at one time flanked by a small lake west of New Elgin, and on the opposite side has been slightly dissected by the Black Burn. Between the Black Burn confluence and Sheriffmills, the alluvium is sandy and the gradient of the river drops to less than 8 ft per mile. There is a nick-point just below the Bow Bridge at Sheriffmills [203632] separating this part of the course from the lower reaches where the deposits of silty sand, silt and clay have spread through the Loch Spynie–Loch of Cotts depression.

Among the smaller spreads of fluviatile alluvium, terraces are seen in the valleys of the Black Burn, the Burn of Fochabers, and the middle course of the Burn of Tynet. Where the terrace above the present Tynet alluvium is dissected by the Aulrothie Burn 200 yd E. of Burnside Cottages [390605] an *in situ* bed of peat 1 ft 6 in thick occurs sandwiched between sand and gravel, probably marking the site of a former lake.

Thin spreads of lacustrine deposits have been mapped at a few localities, particularly in association with flats of marine origin and in basins between mounds of glacial sand. A patch of shell marl occurs on the Mosstowie flat 440 yd due S. of Redhill [162614], and further small areas have been delineated in the Spynie region associated with basin peat. Faunal lists for two localities are given on p. 138. In most cases the marl is less than 2 ft 6 in thick. In this latter locality the marl is possibly a deposit of the historical freshwater Loch of Spynie, now much reduced by drainage. In the south-west corner of the sheet a lacustrine flat south of Hillhead [071598] is underlain by a thin deposit of peat and clay.

PEAT

Most of the peat shown on Sheet 95 occurs in basins, and like the deposits mentioned in the preceding paragraph often marks the sites of former lakes. Hill peat is restricted to a few patches on the higher ground in the extreme south-east. The basin peat frequently contains tree boles and other woody fragments, and in some areas the remains of sedges and freshwater shells. The spreads of peat are probably only a fraction of the original, most of it apparently having been removed for fuel during historical times. The largest areas are south of Hempriggs, at Buthill, and on the south margin of the Loch of Cotts alluvium. At Hempriggs it is reputed to reach a depth of 15 ft, and at Buthills, the depth is certainly greater than 4 ft at some points. Similarly the peat on the south side of the Loch of Cotts alluvium is known to exceed 5 ft in thickness. Crookies Moss [163665] and the Moss of Barmuckity [243610] are two areas where the peat cover has been almost entirely removed.

BLOWN SAND

The largest areas of blown sand face Burghead Bay. Apart from the irregular dune-forms common to most coasts there are sand ridges trending approximately south-west to north-east, well seen north of Kinloss and south of Burghead where they transgress on to late-Glacial beach deposits.[1] The highest dunes have a relief of about 50 ft but inland the amplitude decreases and the mapped areas of blown sand merge with the thin sandy spreads which affect the character of the topsoil as far east as Covesea. Within historic times the migration of sand along the north and west sides of the Loch Spynie alluvial flat materially affected local drainage conditions and accounted for the disappearance of the small lochs of Roseisle, Keam (probably Kaim of Duffus) and Outlet (not identified). This is reputed to have happened when the Culbin Estate farther west was devastated by sand during the late 17th century (Young 1871). The site of the former Loch of Roseisle was probably just north of College of Roseisle, and is marked by a bed of peat some 4 ft thick beneath a similar thickness of sand.

Though much of the blown sand may be redistributed beach sand, carried westwards by the longshore drift and subsequently swept eastward again by the prevailing wind, it is considerably augmented by material derived from the glacial sands. In spite of afforestation, sand continues to drift during high winds in farmland east of the coastal belt, and the results of sand blast are well seen in the fine ventifacts which are strewn on the surface in parts of the Spindle Muir area [150655].

Glacial and Late-Glacial History

In the coastal district of Banffshire east of the area of Sheet 95 Read (1923, p. 186) proposed the following sequence:

(iv) Late Glacial Sands and Gravels
(iii) Upper or Northerly Drift
(ii) Sands, clays and gravels (The Coastal Deposits)
(i) Lower or South-easterly Drift, including the Shelly Boulder-clay and the Bouder-clay with Jurassic Fossils

From his more general work in North-east Scotland Bremner (1928, pp. 147–68) suggested that the Upper or Northerly Drift was succeeded by a further glaciation from the north-west, though, apart from the remarkable section of drifts of Rothes (Bremner 1934, p. 37), the existence of this 'third ice sheet' was deduced mainly from a consideration of retreat phenomena (Bremner 1934, p. 18). In 1956 a further complication was introduced by the discovery that part of Buchan was apparently unglaciated during the later glacial phases (Synge 1956; Charlesworth 1956), though there is evidence of a cold climate in the form of extensive frost shattering and solifluxion. Synge also suggested that a moraine near Lhanbryde, east of Elgin, was a readvance moraine, which he correlated with his 'Aberdeen Readvance' farther south. This readvance 'moraine' (fluvio-glacial deposits) is, in fact, near the limit of the Elgin Oscillation of this memoir, though the evidence on which Synge based his idea (drifts of supposedly differing provenance) has not been substantiated during the present investigations.

A re-examination of critical sections near Portsoy has shown that Read's Lower or South-easterly Boulder Clay is locally underlain by another, highly decomposed till (perhaps representative of a still earlier glaciation followed by

[1] Ogilvie (1923) regards the more northerly of these as parabolic dunes, but much of the evidence has since been modified or obscured by afforestation.

an interglacial period), and that the Coastal Deposits probably overlie the Upper or Northerly Boulder Clay (Peacock 1966).

In the Elgin District much of the till can probably be equated with the Lower or South-easterly Boulder Clay of Banffshire, though the sections showing brown till overlying dark grey till south of Buckie suggest that there may bave been two phases of ice movement involved in areas outside tbe limit of the Elgin Oscillation (see below). The upper till in these sections could be the ground moraine of Bremner's 'Third Glaciation'. Within the limits of the Elgin Oscillation the Lower or South-easterly Drift must have suffered reworking and possibly addition of material, though no evidence of this can be seen, owing, perhaps, to the similarity of the source rocks in each case. The relations of the till derived from tbe south which occurs on the high ground outwith the south and south-east margins of the Elgin District cannot be ascertained directly, but there is little doubt that this till antedates the Elgin Oscillation and can be correlated with the Upper or Northerly Drift of Banffshire (as suggested by Bremner).

Elgin Oscillation. The evidence for the Elgin Oscillation is as follows:

(a) The meltwater deposits and features south and east of Elgin suggest that an ice front stood there for a considerable period

(b) The varved and laminated clays of the Fochabers Glacial Lake are overlain by sandy outwash (Red Burn). Lacustrine deposits exposed by erosion of the River Spey within the probable maximum position of the ice-front occur between Mosstodloch and the Red Burn

(c) The fresh appearance of the glacial topography in the Elgin neighbourhood contrasts with that east and south of Buckie, and with that in the Spey valley from near Fochabers upstream to within four or five miles of Grantown

(d) The evidence of periglacial conditions in the ground south of the readvance limit, such as extensive solifluction of till-covered slopes, and the occurrence of frost wedges in the Spey valley east of Rothes (Sheet 85; C. Romans, personal communication) and in the terrace gravels at the south end of the Glen of Rothes. Such features have not yet been observed north and west of the readvance limit

From the above it seems tbat ice occupied the Elgin area for a considerable period after it had withdrawn from the ground to the east and south, and the evidence further suggests that a readvance took place. It is probable that the readvance was no more than a minor oscillation since no evidence has been found of the incorporation of marine deposits in the glacial outwash as would be expected if the late-Glacial sea had been able to extend far to the west at an earlier date.

The discovery of a buried solifluxion soil dated at 28,000 years B.P. at Tiendland, just south of the readvance limit (Fitzpatrick 1965) is of interest in connexion with the possible significance of the Elgin Oscillation. Though the material overlying this soil is regarded as of purely glacial origin by Fitzpatrick, Soil Survey evidence suggests that this too could be a solifluxion deposit (Romans and others 1966). There is thus a certain amount of support for the view that the district south of the Elgin Oscillation limit has been ice-free since before 28,000 B.P. whereas the ground to the north was certainly ice-covered at the time of the rise of the late-Glacial sea.

TABLE IV

CHRONOLOGY OF GLACIAL RETREAT IN THE ELGIN AREA

Marine Stages (local)	Spey Valley	Meltwater Deposits	Glacial Events
Low Sea Level			Withdrawal of ice from Banffshire Coast and Rothes Area
	Water escapes under or over ice front	Varved and laminated clays, sands, etc., of Fochabers Lake[1]	Readvance of ice to, or stillstand of ice at, Birnie–N. Glen Rothes–Fochabers–Whiteash Hill (Elgin Oscillation)
?High Sea Level	Ordiquish Terrace (lacustrine)	Kame-plateaux of Blackhills Channel Stage (a)	
			—Break-up of Moray Firth Ice
	Orbliston Terrace } Trochelhill Terrace } Balnacoul Wood Terrace }	Kettle-gravels of Blackhills Channel Stage (a)	Embayed ice front Whitewreath–Blackhills–Lhanbryde–Garmouth. Relict ice-cap in Ordiga area east of Spey
Beach at '80 ft'			
Beach at '70 ft' (?)	Mosstodloch Terrace	Fluvio-glacial sands of Blackhills Channel Stage (b)	
Beach at '50 ft' (?)	Lunan Wood Terrace		*In situ* decay of ice with front Whitewreath–Lhanbryde–Garmouth. Disappearance of ice in Ordiga area

[1] Possibly belong to an earlier phase (see text p. 121)

Final withdrawal of the ice. Just after the maximum of the Elgin Oscillation the ice evidently withdrew sufficiently to permit outwash from the Blackhills Channel (shown as Stage (a) in Table IV, p. 120) together with that derived from the ice-front farther north to spread as a series of fans, possibly into the Fochabers Glacial Lake (see below). The outlet of this lake is not clear. It may have been eastwards along the ice-front north of Whiteash Hill, as suggested by Bremner (1934, p. 34), but since the only features and deposits here are associated with ice which stood in the Ordiga area north-east of Fochabers, the water may perhaps have escaped over or under the ice, eventually breaching it along the line of the lower Spey. An alternative suggestion is that the deposits of the Fochabers Glacial Lake were laid down at an earlier stage, i.e. during the wasting of a previous ice-sheet, and that at the time of the Elgin Oscillation the waters of the Spey were able to find their way through or under the ice without a lake being impounded.

At the close of the Elgin Oscillation the sea-level rose relative to the land, and as a result of this, perhaps aided by an influx of slightly warmer water, the land-ice in the Moray Firth rapidly broke up leaving remanié glacier ice in the Spynie, Binn Hill and Ordiga areas. The evidence for the remanié ice, as described on preceding pages, is the presence of kettle-holed sands at and below the 50-ft contour, and the absence of late-Glacial beach features behind the Roseisle–Covesea ridge. Thus while the ice centred on the Binn Hill protected that area from marine action, the north margin of the ice extended westwards behind the Roseisle–Covesea ridge allowing wave attack on the outer coast, and the southern margin extended from Lhanbryde to Longmorn and Heldon Hill. The westward limit is less certain, but may have been near Forres. If the late-Glacial beaches are tilted appreciably, as is suggested by the levelling of a feature in the Grange Hill area (p. 109), the ice mass in the Spynie basin would not have been separated from the main Moray Firth glacier.

After the draining of the Fochabers Glacial Lake, the uppermost terraces of the River Spey were formed with ice still in the vicinity. Both the Trochelhill and Balnacoul Wood terraces (Fig. 17) merge into kettle deposits which may in part be the last spreads of gravels of Stage (a) of the Blackhills Channel. At a somewhat later stage the river which laid down the gravels of the great Mosstodloch Terrace was evidently still in contact with ice not far north of Mosstodloch, and possibly also near Upper Dallachy on the east bank. The terrace near Upper Dallachy falls below 80 ft, and is cut into by a beach with a back-feature near 50 ft O.D. suggesting that the late-Glacial sea had already receded locally from its highest level at the time of deposition.

Before the disappearance of the ice the meltwaters flowing down the Blackhills and other channels had begun to spread deposits, mainly sand, across the decaying ice margin to the north to produce the irregular hummocky sands and lacustrine flats north of Lhanbryde. The sand and gravel of the Binn Hill was, however, probably deposited earlier. The remanié ice finally vanished when the sea-level had locally fallen to 50 ft, and it may be that the Lunan Wood Terrace, the lowest of the upper group of Spey terraces, was formed at this period.

J.D.P.

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Chapter X

ECONOMIC GEOLOGY

Building and Road Material

The various sandstones of the Upper Old Red Sandstone and the New Red Sandstone have been extensively worked in the past both for building stone and roadstone. At present, however, operations are confined to two quarries in the Hopeman sandstone. West of Hopeman the long-established Greenbrae Quarry is currently being worked on a small scale for building stone. The sandstone with fluorspar cement, which occurs mainly in the more northerly part of the quarry, is rejected as are those parts of the rock affected by the east-west-trending siliceous and ferruginous structures. Variations in degree of cementation and the presence of patches with iron oxides, both of which affect the coloration and weathering properties of the stone, may make the rock unsuitable for building. The sandstone, which hardens on exposure, can be obtained in large blocks bounded by joints and by planes of aeolian cross-bedding. Similar yellow-brown sandstone is worked at Clashach Quarry on the coast east of Hopeman (p. 61). The building stone is used locally, in the south of Scotland, and as far afield as Sweden.

Of the disused quarries, those in the Rosebrae Beds of Quarry Wood and Bishopmill near Elgin seem to have yielded the most building stone (Young 1879) and probably contain the greatest reserves. The Alves Beds at Burgie, Alves, and Newton formerly supplied material more suitable for field walls and millstones, as did the Millstone Quarry in the Cutties Hillock (Quarry Wood) sandstone (p. 73). Quarries in the Upper Triassic sandstone at Spynie were probably intermittently worked from very early times, their last phase of activity coinciding with the building of railways in Morayshire.

East of the Spey roofing slates were formerly quarried at Tarrymount Quarry [411585] in the Findlater Flags, and the Cairnfield Actinolitic Flags locally yielded building stone.

Limestone

The cornstones in the Upper Old Red Sandstone south and east of Elgin and the Triassic cherty limestone at Inverugie were worked for lime before the building of the railways in the latter half of the 19th century led to the importation of better quality material. A partial analysis of cornstone from Stonewells [280656] east-north-east of Elgin shows 88·5 per cent of calcium carbonate (Robertson and others 1949). This exposure is now entirely obscured. Farther east the limestone in the Buckie Beds of the Middle Old Red Sandstone between Buckie and the Gollachy Burn was worked on a small scale until the mid-19th century (Wallace 1880, p. 336).

Sand and Gravel

As shown on the Drift edition of the one-inch map of the Elgin District superficial deposits, including extensive sheets of sand and gravel, are widespread.

The glacial and fluvio-glacial sands and gravels which cover much of the lower ground vary greatly in lithology. In general it appears that west of the Spey and north of a line from Garmouth to Lhanbryde and Birnie, soft well-sorted sands predominate, though these in places contain interbedded silts. South and east of the line the deposits tend to be coarser and gravelly. The reserves are considerable. Details of exposures are given in Chapter IX and by Anderson (1943, pp. 22–3).

The major sources of gravel in the district are the storm beaches which stretch intermittently from Portgordon to the western edge of the sheet near Kinloss (Plate IV). The deposit is in the form of gravel ridges in which the pebbles, dominantly of Moine granulite and quartzite, have been well sorted by wave action. In spite of local extensive working, e.g. west of Garmouth and south of Lossiemouth, the reserves appear to be great, and exploitation is limited only by land use and by the height of the water-table. Details of exposures can be found on p. 110 and descriptions of others not now seen are given by Anderson (1943, p. 22).

Brick Clay

Silty clay of marine origin underlies parts of the Spynie depression. Much of the deposit is only a few feet above Ordnance Datum, but on the north side of the depression it rises to about 25 ft O.D. a little south of Duffus. The clay was formerly worked for bricks and tiles near Gilston [207662] and at a locality [232672] east of Ardivot. At the latter a thickness of 48 ft of clay was penetrated by digging and boring without the bottom being reached, and at the former some 42 ft. A Geological Survey borehole at East Mains a little north of Gilston penetrated 65 ft of clay before entering till (p. 132). Similar clay is exposed at the former Loch of Cotts north of Milltown Airfield. The reserves of clay would thus appear to be very large, though difficult to exploit at some localities.

Much of Lossiemouth Airfield is underlain by glacio-marine clay, some or all of which may be suitable for brick manufacture (Eyles and Anderson 1946, pp. 22, 39). The glacio-lacustrine silts and clays common in the western half of the Elgin District do not appear to have been recently tried for brick-making, but the reserves at any one locality do not appear to be great.

Peat

Owing to extensive working in the past and the present claims of agriculture and forestry over the remaining ground underlain by peat, exploitation of this material, other than on a very small scale, has been discontinued.

Mineralization

West of the Spey, galena-hematite-fluorspar-barytes-calcite-quartz mineralization is widely distributed, and is associated especially with the Cherty Rock and the faults and joints affecting this and older rocks. At Stotfield [229710] galena

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PLATE IV

GRAVEL QUARRY HALF A MILE SOUTH OF LOSSIEMOUTH, EAST OF THE LOSSIEMOUTH ROAD
View looking east. Depositional dip in shingle of raised storm beach (D 677)

was worked for a time about 1880 on a small scale (Wilson and Flett, 1921, pp. 110–11) but neither this nor earlier attempts (Gordon 1859, p. 47) appear to have met with much success. Galena in specimen quantities occurs at various localities, e.g. at Spynie, at Inverugie and in the fault zone just west of Masonhaugh Quarries near Burghead. It has also been recorded from the Alves Beds at the west end of Carden Hill.

The possibilities of extraction of fluorspar from the Hopeman and Lossiemouth sandstones have been considered by the Geological Survey (Dunham and Wilson *in* Dunham 1952, pp. 125–7). Though the resurvey has extended the known area of fluorspar-bearing sandstone (Fig. 14), the possibilities of exploitation still seem to be limited by the patchy distribution of the mineral and the invariable presence of a high percentage of sand grains even in the best grade of material. Fluorspar in small amounts also occurs in cavities in the Upper Old Red Sandstone at Lossiemouth and was found by Mackie (1923, p. 159) at Cutties Hillock, Quarry Wood.

The distribution of barytes as a cementing substance in the western half of the Elgin District is shown in Fig. 14. It is also found on joint surfaces, being particularly common in the Lossiemouth quarries where it is associated with fluorspar.

A lower limit to the age of the mineralization in the Lossiemouth area is given by the occurrence of several joint surfaces coated with fluorspar and galena in the Lower Jurassic rocks penetrated by the Geological Survey Lossiemouth borehole (p. 134). Moorbath (1962, p. 335) gives a date of 140 ± 60 million years for the galena at Stotfield. It would appear that the Cherty Rock under its presumed capping of impervious Jurassic strata favoured deposition of galena, and this factor should be taken into account during any future assessment of the area for economic metalliferous minerals.

East of the River Spey disseminations and veinlets of barytes occur on the coast between Portessie and Gollachy in the Cullen Quartzite, in the conglomerates of the Middle Old Red Sandstone, and in the Buckie Beds. The age of this mineralization is not known.

Water Supply

Most of the water requirements of the Elgin District are supplied from surface catchments such as the Glen Latterach Reservoir in the adjacent area of the Rothes (85) Sheet and from the River Spey. Underground sources are utilized locally, however, and in some areas contribute substantially to the water supply.

In the west of the area, at Glenburgie Distillery, a plentiful water supply is obtained from near the contact of the Upper Old Red Sandstone with the Moine Schists, but none is known to be derived from the Moinian or Dalradian rocks themselves. Farther east, at Oakwood, on the main road about two miles west of Elgin, a deep bore in the Upper Old Red Sandstone has yielded water for a local supply. Springs in the Burghead Beds near or at the faulted contact with the Hopeman sandstone are located at St. Aethan's Well, east of Burghead, at Roddoch Wells, Cummingstown, and at St. Peter's Well, Duffus, though only the latter is now much used. Water possibly associated with the same fault was tapped in a Geological Survey borehole on Lossiemouth Airfield (p. 134).

Before the introduction of piped water many of the farms obtained supplies from wells and springs in the superficial deposits, but only a few of these are now used. Three, however, still contribute substantial quantities, viz. wells in the Blackhills Channel half a mile south-west of Blackhills House, Coxton Springs, Lhanbryde, and St. Bennett's Well, Duffus. East of the Spey, springs about half a mile west of Cairnfield House contribute to the water requirements of the coastal district.

Lossiemouth formerly obtained water from the storm beach gravels at wells sited within the town, and at Kinloss similar gravels also yield potable water. In both cases overpumping would probably result in contamination by sea water.

West of Elgin a line of springs yielding small supplies of water extends north-east and south-west from Rosebrae and marks the contact of glacio-lacustrine clays with the sandier drift of the Quarry Wood–Carden Hill ridge.

Soils

Farming and forestry are important in the Elgin District; these activities depend partly on the geology in that the distribution of soil types reflects to a great extent the variety of superficial deposits which cover the lower ground. It is only on the higher ground in the south-east corner of the district and on hills and ridges elsewhere that the soil rests on solid rock. Thus the best agricultural land is associated mainly with the glacio-lacustrine silts and clays and with the various fresh-water and marine alluvial deposits of silt and clay grade. Drainage conditions, however, have a marked effect on their exploitation, particularly in low-lying areas such as the Spynie basin. Mature souls tend to be podsols, and those derived from glacial and fluvio-glacial sands are often characterized by a horizon of iron-pan. The poorest soils are commonly associated with the coastal storm beach gravels, with some of the fluvio-glacial and alluvial gravels of the Spey valley, and with the higher ground underlain by stonier tills and solid rock. A comprehensive account of the soils of the Elgin District is given by Grant (1960). J.D.P.

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Appendix I

Geological Survey Boreholes

Following the resurvey of the Elgin (95) Sheet four shallow boreholes were drilled by Messrs. John Thom Ltd. in 1964–65 to help to elucidate the stratigraphy, structure, and distribution of the Permo-Triassic and Upper Old Red Sandstone rocks and to gain further information about the drift deposits within the Spynie depression. A fifth borehole was drilled on Lossiemouth Airfield to investigate occurrences of unusual rock types found in certain engineering bores. The Jurassic strata found on drilling this borehole have already been fully reported elsewhere (Berridge and Ivimey-Cook 1967) and the results are discussed in Chapter VII, p. 77, and Chapter IX, p. 108.

Clarkly Hill (No. 1) Borehole ([12706833], 179 ft O.D.)

There are no exposures within the Elgin District showing either the full succession of the Sandstones of Hopeman or that of the Burghead Beds, and the relationship of the two rock groups, both presumably of Permo-Triassic age, is not evident from surface exposure. From the attitude of the faulted contact on the coast it can be argued that the Burghead Beds are younger than the Hopeman sandstone. Since different hypotheses concerning these rocks would affect their postulated distribution in ground largely concealed by drift it was decided to drill on Clarkly Hill, at a locality where it was expected that most of the thickness of the Burghead Beds would be intersected. An abridged section of the borehole with the most likely geological classification is given below.

	Thickness		Depth	
	Ft	in	Ft	in
PERMIAN AND TRIASSIC				
Burghead Beds				
7. Sandstone, friable, cross-bedded, yellow-brown to greyish-brown, fine- to coarse-grained, with bands of pebbles, poorly cemented. Thin beds of silt and clay, horizons of silt pellets. Dip 5 degrees	136	6	136	6
6. Sandstone, friable, greyish-orange to pale grey, fine- to medium-grained. Pyritic cement below 175 ft depth ..	101	6	238	0
Sandstones of Hopemon				
5. Sandstone, medium- to coarse-grained, friable, dune-bedded	109	0	347	0
4. Sandstone, friable, medium- to coarse-grained, gritty. Quartz pebbles frequent towards base. Sets of cross-bedding up to 16 ft thick	88	0	435	0
3. Interbedded sandstone and siltstone. Many pebbles ..	3	0	438	0

presumed unconformity

OLD RED SANDSTONE

Upper	Thickness		Depth	
	Ft	in	Ft	in
2. Sandstone, fine-grained, brownish-grey, firm; and muscovitic sandy siltstone, firm	28	0	466	0
1. Sandstone, marly, reddish-brown, coarse-grained, interbedded with light grey sandy siltstone and fine-grained sandstone. Dip 12–15 degrees	7	0	473	0

From the summary it can be seen that the borehole, which began near the top of the Burghead Beds, passed through aeolian sandstone into strata resembling the Rosebrae Beds of Quarry Wood. Whilst the sandstones down to 136 ft in depth (bed 7) are identical with the Burghead Beds at Burghead, the sandstone following (bed 6) is free of pebbles, and except for the occurrence of small-scale cross-bedding, resembles the Hopeman sandstone, for example in the occurrence of millet-seed sand grains. The lowest stratum of bed 6 contains many galls of green clay. Apart from traces of carbonate at a few horizons the sandstones are much leached and sparsely cemented only by red-brown and yellow-brown iron minerals, rarely occurring as nodules, to a depth of about 175 ft below the top of the bore. Below 175 ft the iron ore is pyrite.

Bed 5, which appears to be a single set of dune-bedding, is a massive to laminated sandstone with grains of high sphericity and roundness, and kaolinized feldspars are prominent. There are scattered small clay galls in the bottom 40 ft. The underlying bed 4 is similar, but includes a number of sets of cross-bedding. Pebbles, many of which are faceted, become common towards the base, and are prominent also in bed 3. Some of the rocks in this part of the bore are cemented by calcite in addition to the sparse pyrite. The characteristics of beds 3 to 5 are those of the Sandstones of Hopeman and Cutties Hillock (Quarry Wood), and the pebbly sandstones at the bottom of the succession are doubtless equivalent to the pebble-bed at the base of the Cutties Hillock sandstone.

The identification of beds 1 and 2 as belonging to the Old Red Sandstone rests on the occurrence of sandstones with galls of red and green clay, which can be matched both in the Rosebrae Beds below the Cutties Hillock sandstone, and in the undivided Upper Old Red Sandstone west of Lossiemouth which presumably underlies the Hopeman sandstone in that area. The occurrence of oxidized strata below sandstone with pyritic cement is confirmatory evidence of a discontinuity. Both siltstones and sandstones are firm, in contrast to the overlying friable rocks, and contain varying proportions of muscovite, a mineral scarce or absent above. The siltstone below the presumed unconformity preserves well-marked ripple lamination.

No fluorspar-barytes-galena-mineralization was seen in the borehole core. One small fault noted near the base of bed 5 is accompanied by a thin gouge of clay and pyrite.

The Clarkly Hill Borehole thus confirms the suggestion that the Hopeman sandstone underlies the Burghead Beds, and also shows that these two divisions are in stratigraphical continuity. Extrapolating the succession in the borehole it seems likely that the combined Burghead Beds and Hopeman sandstone reach a maximum thickness of about 500 ft below the Cherty Rock (exposed at Inverugie, not far east of Clarkly Hill).

Spynie Quarry (No. 2) Borehole ([22286559], 84 ft O.D.)

Apart from sparse outcrops of water-laid beds below the Lossiemouth sandstone little is seen of the strata underlying the known Upper Triassic rocks, though it could be surmised that these might include elements of the Burghead Beds and Sandstones of Cutties Hillock (Quarry Wood). Westoll (*in* Watson 1948), however, reported Old Red Sandstone in temporary excavations not far below the Lossiemouth sandstone. It was hoped that a borehole at Spynie Quarry, starting in rocks of known age, would help to prove the succession. The following is an abridged log of the borehole with suggested classification.

	Thickness Ft	Thickness in	Depth Ft	Depth in
TRIASSIC				
10. Sandstone, pinkish grey (5 YR 7/1), siliceous at top, calcareous below	31	6	31	6
9. Siltstone and fine-grained sandstone, grey, pinkish, and pale orange (10 YR 7/2–8/2), calcareous. Dip 5–7 degrees	20	9	52	3
8. Sandstone, brownish yellow, fine- and coarse-grained, interbedded with siltstone; calcareous. Grey, brown, and violet at base	6	1	58	4
OLD RED SANDSTONE				
Upper				
7. Siltstone and fine-grained sandstone with gritty laminae, greyish red (10 R 4/2) and brownish yellow (10 YR 6/4). Galls of green clay. Slightly calcareous in lower part. Dip 7 degrees	17	8	66	0
6. Sandstone, fine- to coarse-grained, brownish yellow, friable, with bands of pebbles. A little mica. Calcareous cement in part. Dip 5 degrees	59	6	125	6
5. Sandstone, fine-grained, mainly reddish brown (10 R 3/4), with stripes of marly siltstone	5	0	130	6
4. Sandstone, brownish grey (5 YR 6/3–7/4), fine- to coarse-grained, with pebble band at base	6	9	137	3
3. Sandstone and siltstone, reddish brown and brownish grey, partly marly, rarely pebbly, with a few clay galls. Ripple lamination and load casts. Dip 5 to 8 degrees	52	3	189	6
2. Sandstone, fine-grained and coarse-grained, brownish grey to orange, cross-bedded, with bands of pebbles and a clay band. A few spots of barytes. Some calcareous cement and ferruginous nodules. Dip 8 degrees	16	6	206	0
1. Sandstone, fine- to medium-grained, brownish and greenish grey, with very sparse pebbles of quartz and galls of green clay. Colour banding and brecciation at base (*fault*)	29	0	236	0

Bed 10 is the continuation of the sandstone in the quarry face above the top of the borehole, and bed 9 is probably the main source of the reptile fossils formerly found in the deeper openings at Spynie. The strata from the top of bed 7 to bed 2 resemble the Burghead Beds at Clarkly Hill (see above) to some extent, but include reddish-brown marly sandstones like those seen in parts of the Upper Old Red Sandstone. The lowest few feet of sandstone in the bore differ little from the Rosebrae sandstone exposed at Bishopmill Quarry near Elgin and are therefore taken to be definitely of Upper Old Red Sandstone age.

In the absence of fossil evidence and of angular unconformity it is not clear where the line should be drawn between the Triassic rocks and the Upper Old Red Sandstone. The only marked break in lithology is at the base of bed 8 where the calcareous strata are succeeded abruptly downwards by non-calcareous siltstone and then by reddish-brown marly sandstone. If it is accepted that the junction of the Triassic and the Upper Old Red Sandstone is between beds 7 and 8 then the pebbly and marly sandstones (beds 2 to 7) may well be stratigraphically higher in the Old Red Sandstone succession than the Rosebrae Beds of Bishopmill Quarry. The Cutties Hillock sandstone is not present, and the Burghead Beds, if they occur, can be represented by only 6 ft of sandstone. From the base of bed 8 to the base of the Cherty Rock exposed at the top of the quarry is 100 ft, and the total thickness of the New Red Sandstone in the neighbourhood can scarcely exceed 115 ft, compared with over 500 ft near Burghead. Since holoptychian remains occur in sandstone at Findrassie (p. 51) which is sandwiched between the Bishopmill and Upper Triassic sandstones, there is further support for the view that beds 2 to 7 are of Old Red Sandstone age, though at the same time it should be noted that the Findrassie sandstones are highly siliceous.

East Mains (No. 3) Borehole ([20446672], 6 ft O.D.)

The bore at East Mains was intended to provide a section through the drift deposits of the Spynie basin, known to be about 100 ft thick from geophysical evidence, and it was hoped also to be able to identify the underlying solid rock. Unfortunately, only about two-thirds of the core was recovered above the level of the till, and little excepting sludge was brought up between 68 and 107 ft. Thus, though the drift log probably gives a good representation of the gross lithology, horizons of small thickness may have been overlooked. The following is an abridged log of the bore:

	Thickness Ft	Thickness in	Depth Ft	Depth in
DRIFT				
8. Sand, grey, medium-grained, with numerous pebbles. Shell fragments	3	3	3	3
7. Interbedded olive-grey clay and sand, pebbly near top. Shell fragments	23	9	27	0
6. Clay, silty, olive-grey, with a thin silt layer at the top. Locally faintly colour-laminated	41	0	68	0
5. Till, olive-grey to brownish grey, sandy	15	0	83	0
4. Till, dark grey	2	0	85	0
3. Sand and gravel, clean	22	0	107	0
OLD RED SANDSTONE				
Upper				
2. Sandstone, fine-grained, reddish brown (10 R 4/5) with scattered pebbles	16	0	123	0
1. Sandstone, reddish brown, micaceous, with bands of marl. Pellets of marl in some of the sandstones. Dip nearly horizontal	23	0	146	0

Bed 8 is probably a recent deposit, perhaps dating from the period before tbe 14th Century when the Locb of Spynie was tidal. The shell marl and basin peat, which occur near Gilston some 400 yd to the south, are absent here and the deposit is probably entirely near-shore marine. The underlying interbedded shelly sand and clay (7) probably also belongs to the post-Glacial marine transgression, but the silty clay (6) witb sparse faunal remains is a fringe-marine estuarine deposit resembling the carse clays of the Forth valley, and may be of late-Glacial age. A faunal list is given in Appendix II, p. 138.

Little was recovered of the brownish grey till (5) but there is little doubt that it can be referred to the normal brown till of the Elgin District. The dark grey till (4) has a clayey matrix derived from black shale, fragments of which, with lamellibranch shells, are frequent in the coarser fractions together witb psammite, oolite, cornstone and granite. Black shale fragments are also sparingly distributed in the clean sand and gravel below, which may be outwash from the advancing ice which deposited the dark till.

The solid rock intersected by the borehole can be equated with the Old Red Sandstone, probably the Upper division, and tbus the fault, known to occur between the Lossiemouth and Findrassie areas, must lie south of the borehole site.

Rosebrae (No. 5) Borehole ([17376416], 86 ft O.D.)

The object of the bore at Rosebrae was to determine whether the Rosebrae Beds occur below the low-lying ground north of Quarry Wood. If so, the geological relations would suggest that a branch of the Rothes Fault separates the Alves Beds of the Newton group of quarries from the Rosebrae Beds of Quarry Wood. On the other hand, if tbe borehole intersected Alves Beds, the geological relations could be satisfactorily explained without faulting (e.g. Fig. 12, p. 46). A summary of the Rosebrae Bore is as follows:

	Thickness		Depth	
	Ft	in	Ft	in
DRIFT				
2. Till, boulders of the underlying sandstone	13	6	13	6
OLD RED SANDSTONE				
Upper				
1. Sandstone, buff and red-brown, friable to well cemented, varying from fine- to coarse-grained. Numerous green and red clay galls at some horizons and pellets of green micaceous siltstone. Scattered small quartz pebbles in upper part. Dip less than 5 degrees ..	38	6	52	0

The solid rock in the borehole, though less pebbly than the Alves Beds exposed at Newton Quarries, is unlike the typical fine-grained Rosebrae sandstone exposed on the slopes of Quarry Wood hill. It resembles, bowever, tbe beds seen below Rosebrae-type sandstone in a borehole core taken from near the Newton–New Spynie road higher up the slope, between the Rosebrae Borehole and Quarry Wood. On balance therefore it is reasonable to place the solid rock of the Rosebrae bore in the Alves Beds, probably not far below their junction with the Rosebrae Beds.

Lossiemouth (No. 4) Borehole ([21586986], 19 ft O.D.)

The purpose of the Lossiemouth Borehole was to investigate occurrences, in engineering bores, of strata distinct from the other sedimentary rocks examined in the Elgin District. After passing through drift the bore entered rocks now known to be of Lower Liassic age. The following is a summary of the borehole section, the solid rocks of which are described in more detail in Chapter VII, p. 77, and the drift commented on in Chapter IX, p. 108. For a more extended account of the geology of the borehole the reader is referred to the paper by Berridge and Ivimey-Cook (1967). Faunal lists are given in Appendix II, p. 137.

	Thickness Ft	Thickness in	Depth Ft	Depth in
DRIFT				
9. Sandy soil	1	6	1	6
8. Micaceous sand with horizons of silt and clay. Shell fragments	5	6	7	0
7. Olive-grey, silty clay with a few sandy horizons	20	0	27	0
6. Olive-grey, silty pebbly clay, merging into yellowish sandy till	11	6	38	6
5. Dark grey till composed dominantly of shale fragments	3	6	42	0
JURASSIC				
4. Sandstone, pale yellowish-grey, for the most part kaolinitic; sparsely occurring plant debris	56	3	98	3
3. Sandstone, siltstones, mudstones and shales, generally grey, often bioturbated or otherwise disturbed, much plant debris near the top	123	3	221	6
2. Marls and cementstones, respectively greenish-grey and olive-grey, alternating sequence	30	10	252	4
1. Marl, greenish-grey with some subordinate cementstone nodules	17	8	270	0

J.D.P.

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Appendix II

LIST OF FOSSILS RECORDED FROM THE AREA

THE following list has been arranged in ascending stratigraphical order, giving the localities in alphabetical order, with the faunas recorded from them, and the depositories in which specimens are stored. The abbreviations used for the names of the depositories are as follows—Aberdeen University (Marischal College) (A), British Museum (Natural History) (BM), Cambridge University (Zoology Department) (CZ), Albert Museum, Dundee (D), Elgin Museum (E), Forres Museum (F), Geological Survey, Edinburgh (GSE), Geological Survey and Museum, London (GSM), Hunterian Museum, Glasgow (H), Kelvingrove Museum, Glasgow (K), Manchester Museum (M), Newcastle University (N), Royal Scottish Museum, Edinburgh (RSM), Sedgwick Museum, Cambridge (S).

There are probably other collections from the area, as some occurrences of species quoted in early literature cannot now be traced.

MIDDLE OLD RED SANDSTONE

DIPPLE BRAE, section 590 yd N. 15° E. of Dipple, [33025887] and nearby. *Dickosteus thrieplandi* Miles and Westoll, F, GSE, N, RSM. *Osteolepis sp.*, BM, GSE.

BURN OF GOLLACHY, about 200 yd W. of Auchentae, [410640]. *Coccosteus cuspidatas* Miller *ex* Agassiz M.S., CZ, RSM. *Pterichthyodes miller* (Agassiz), RSM.

BURN OF TYNET, downstream from Lower Mills of Tynet, [383619]. *Cheiracanthus latus* Egerton, BM, D, E, GSE, GSM, H, RSM. *C. murchisoni* Agassiz, BM, E, GSE, GSM, RSM. *Coccosteus cuspidatus*, BM, E, GSM, RSM. *Diplacanthus longispinus* Agassiz, GSM. *D. striatus* Agassiz, BM, D, E, GSE, GSM, RSM. *Dipterus valenciennesi* Sedgwick and Murchison, BM, RSM. *Glyptolepis leptopterus* Agassiz, BM, D, E, GSE, GSM. *Gyroptychius agassizi* (Traill), BM, E, GSM, RSM. *G. microlepidotus* (Agassiz), BM, H, RSM. *Mesacanthus pusillus* (Agassiz), BM, E, GSE, H, RSM. *Osteolepis macrolepidotus* Agassiz, BM, E, GSE, GSM, H, M, RSM, S. *Pterichthyodes milleri*, BM, E, RSM. *P. productus* (Agassiz), BM, RSM. *Rhamphodopsis trispinatus* Watson, RSM.

UPPER OLD RED SANDSTONE

ALVES WOOD. Quarry, possibly that recorded by Linn (on Geological Survey six-inch map Elgin 11, 1887) at 730 yd W. 28° N. of Toreduff, [11446097]. *Holoptychius sp.*, GSE.

ARDGYE. Quarry 1020 yd E. 14° S. of house, [16006307]. *Holoptychius sp.*, GSE, RSM. Linn (on Geological Survey six-inch map Elgin 7, 1887) also recorded *Bothriolepis*.

BISHOPMILL QUARRY, 140 yd W. 12° N. of Woodlands, [208640]. *Holoptychius flemingi* Agassiz, RSM. *H. giganteus* Agassiz, RSM. *H. nobilissimas* Agassiz, E, RSM.

BURGIE, [090590]. Traquair (1897, p. 384) recorded *Bothriolepis* and *Holoptychius* from a locality nearby, specimens cannot be traced.

CARDEN HILL, several localities exist including Quarry 620 yd due S. of Ardgye, [15026269]. *Bothriolepis sp.*, GSE. Carden Hill Quarry, possibly the same locality as the last, *Bothriolepis gigantea* Traquair, RSM. Carden Hill, exact localities unknown. *Bothriolepis alvesiensis* Stensiö, RSM. *B. gigantea*, RSM. *Holoptychius giganteus*, GSM. *Conchodus sp.*, E. Carden Moor Quarry, locality unknown. *Bothriolepis gigantea*, RSM. *Holoptychius sp.*, E.

CARDEN MOOR RAILWAY CUTTING, probably the exposure 750 yd E. of Alves Station, [144619]. *Bothriolepis gigantea*, E.

CARSEWELL QUARRY, possibly the quarry 700 yd E. 13° N. of Carsewell, [140622]. *Bothriolepis sp.* [fragments], K.

CLOVES, possibly the line of old quarries 390 yd due N. of Cloves and nearby, [139616]. *Bothriolepis gigantea*, E.

COOPERS DITCH. Linn (on Geological Survey six-inch map Elgin 2, 1887) recorded *Holoptychius* and *Bothriolepis* from an exposure 830 yd E. 4° S. of North Green, [21607043], no longer exposed. Debris from a trench at this locality yielded fish fragments, GSE.

CROOK OF ALVES, Quarry near, possibly the same quarry as that noted under Carsewell. *Bothriolepis gigantea*, RSM.

CUTTIES HILLOCK QUARRY, 800 yd S. of Loanhead, [185638]. *Holoptychius nobilissimus*, E.

FINDRASSIE, Quarry on north side of road, probably that 650 yd. S. 5° E. of Mains of Findrassie, [19576438]. *Holoptychius sp.*, RSM.

HOSPITAL QUARRY, 960 yd S. 26° W. of Laverockloch, [188629]. *Holoptychius sp.*, GSM. *Phyllolepis concentrica* Agassiz, BM, RSM.

KNOCK OF ALVES, probably the quarry known as York Tower quarry 530 yd W. 15° N. of Knock, [162629]. *Holoptychius sp.*, RSM.

LAVEROCKLOCH QUARRY, 330 yd E. 30° S. of Laverockloch, [195636]. *Bothriolepis sp. nov.*, RSM. *Glyptopomus elginensis* Jarvik, E. *Holoptychius nobilissimus*, RSM. *Phyllolepis concentrica*, BM, RSM.

LEGGAT QUARRY, 1000 yd due S. of Dykeside, [176635]. *Holoptychius nobilissimus*, GSE.

MILLSTONE QUARRY, 990 yd E. 19° N. of Alves Station, [144621]. *Holoptychius giganteus*, RSM. *Psammosteus sp.*, E.

MILTONBRAE, hole at roadside near farm, exact locality unknown. Taylor (1910, p. 47) records *Bothriolepis*, *Holoptychius* and *Psammosteus*, specimens cannot be traced.

NEWTON QUARRIES, consists of a group of quarries north and south of the Elgin–Forres road and 200–300 yd W. and NW. from Newtonroad, [167632]. *Bothriolepis alvesiensis*, RSM. *B. gigantea*, E, F, RSM. *Dendrodus sp.*, RSM. *Holoptychius giganteus*, BM, F, RSM. *H. nobilissimus*, RSM. *Psammosteus megalopteryx* Trautschold, BM, E, F, GSM, RSM. *Polyplocodus sp.*, BM. *Sauripterus spp.*, RSM.

OAKBRAE QUARRY, exact locality unknown. *Holoptychius sp.*, RSM.

PLUSCARDEN, Quarries to the north-west, including a quarry 490 yd N. 26° W. of Foresterseat, [15635352] (on one-inch Sheet 85). *Bothriolepis cristata* Traquair, GSE. *Glyptopomus elginensis*, GSE. *Holoptychius sp.*, GSE. Exact locality of specimens labelled Pluscarden unknown. *Holoptychius sp.*, E, RSM.

REDHALL QUARRY, 780 yd E. 30° S. of Stynie, [341603]. *Bothriolepis paradoxa* (Agassiz), E, RSM. *Holoptychius sp.*, RSM.

ROCKY PARK, ALVES, exact locality unknown. *Bothriolepis gigantea*, E, RSM. *Holoptychius giganteus*, E, RSM. *H. nobilissimus*, RSM.

ROSEBRAE QUARRY, 800 yd S. 12° E. of Rosebrae, [174633]. *Bothriolepis alvesiensis*, GSE. *B. cristata*, E, RSM. *Glyptopomus elginensis*, E, RSM. *Holoptychius nobilissimus*, RSM. *Phaneropleuron andersoni* Huxley, E, RSM. *Phyllolepis concentrica*, BM, RSM. *Rhynchodipterus elginensis* Säve-Söderbergh, E.

SWEETHILLOCK QUARRY, possibly the quarry, now filled, 390 yd N. 5° E. of Sweethillock, [13736148]. *Bothriolepis gigantea*, E. *Holoptychius giganteus*, RSM.

PERMIAN

CUTTIES HILLOCK QUARRY, 800 yd S. of Loanhead, [185638]. *Elginia mirabilis* Newton, E, GSE, RSM. *Geikia elginensis* Newton, E, GSM. *Gordonia duffiana* Newton E. *G. huxleyana* Newton, E, GSE. *G. juddiana* Newton, E. *G. traquairi* Newton, E, GSE.

YORK TOWER QUARRY, 630 yd W. 15° N. of Knock, [162629]. Dicynodont (*Geikia ?*), N.

TRIASSIC

FINDRASSIE QUARRY, probably the quarry 1060 yd due E. of Findrassie, [205651]. *Ornithosuchus longidens* (Huxley), E. *Stagonolepis robertsoni* Agassiz, A, E, GSE, GSM, N, RSM.

LOSSIEMOUTH EAST QUARRY, a long quarry 1350 yd NE. of Coulardbank and nearby, [236707]. *Hyperodapedon gordoni* Huxley, BM. *Leptopleuron lacertinum* Owen, E. BM. *Ornithosuchus longidens*, BM. *Stagonolepis robertsoni*, E.

LOSSIEMOUTH WEST QUARRY, 800 yd E 38°N of Coulardbank, [231706]. *Brachyrhinodon taylori* Von Huene, BM, RSM. *Hyperodapedon gordoni*, M. *Leptopleuron lacertinum*, BM, E, N, RSM. *Ornithosuchus longidens*, BM, E, M. *Saltopus elginensis* Von Huene, BM. *Scleromochlus taylori* A. S. Woodward, BM. *Stenometopon taylori* Boulenger, BM.

LOSSIEMOUTH QUARRIES, exact locality of specimens unknown. *Brachyrhinodon taylori*, BM, E. *Erpetosuchus granti* Newton, BM, E. *Hyperodapedon gordoni* BM, E. *Ornithosuchus longidens*, BM. *Scleromochlus taylori*, BM. *Stagonolepis robertsoni*, A, BM, D, E, GSE, GSM, N, RSM.

SPYNIE QUARRY, probably the quarry 930 yd W 6°N of Spynie, [223658]. *Leptopleuron lacertinum*, RSM.

SPYNIE QUARRIES, exact locality unknown. *Hyperodapedon gordoni*, N. *Leptopleuron lacertinum*, GSM, N. *Ornithosuchus longidens*, BM, GSM.

JURASSIC

The spores have been identified by Dr. W. G. Chaloner, the ammonites by Prof. D. T. Donovan, the ostracoda by Dr. F. W. Anderson and the remaining fauna by Dr. H. Ivimey-Cook. The specimens are housed in the Geological Survey Office, Edinburgh.

LOSSIEMOUTH GEOLOGICAL SURVEY BORE, 900 yd W. 38° N. of Kinneddar [21586986]. Jurassic spores from between 99 ft 2 in and 125 ft 8 in. *Classopollis torosus* (Reissinger) Balme, *Gleicheniidites senonicus* Ross, *Lycopodiumsporites clavatoides* Couper, *Monosulcites minimus* Cookson, *M. sp.*, *Perinopollenites elatoides* Couper, *Pteruchipollenites microsaccus* Couper, *P. thomasii* Couper, and *Sphagnumsporites sp.*

Lower Lias, including *Echioceras raricostatum* Zone, from 120 ft to 194 ft 2 in. *Piarorhynchia sp.*, *Spiriferina?* (juv.), *Bourguetia?*, *?Katosira periniana* (d'Orbigny), *Striactaeonina avena* (Terquem), *Zygopleura* cf. *verrucosum* (Terquem), *Astarte cingulata* (Terquem), *A. sp.*, *Bakevellia sp.*, *Camptonectes lohbergensis?* (Emerson), *C. mundus?* Melville, *C. sp.*, *Cardinia attenuata* (Stutchbury), *C. sp.*, *Ceratomya gibbosa* (Etheridge), *C. sp.*, *Cercomya?*, *Chlamys subulata* (Münster), *C. textoria* (Schlotheim), *C. sp.*, *Dimyopsis?*, *Entolium liasianum* (Nyst), *E. sp.*, *Grammatodon insons* Melville, *G.* cf. *intermedius* (Simpson), *G. sp.*, *Gryphaea sp.*, *Hippopodium ponderosum* J. Sowerby, *Homamya* cf. *venulithis* Troedsson, *H. sp.*, *Lima* (*Plagiostoma*) *sp.*, *Liostrea hisingeri* (Nilsson), *L. irregularis* (Münster), *L. sp.*, *Lucina* cf. *cardioides* Tate, *L. sp.*, *Mactromya arenacea* (Terquem), *Meleagrinella olifex* (Quenstedt), *M. sp.*, *Modiolus* cf. *hillanoides* (Chapuis and Dewalque), *M. laevis* J. Sowerby, *M. sp.*, *Nucula?*, *Oxytoma inequivalve*

(J. Sowerby), *O. sp.*, *Parallelodon sp.*, *Pholadomya sp.*, *Pinna sp.*, *Pleuromya* cf. *oxynoti* Quenstedt, *Plicatula hettangiensis* Terquem, *P.?*, *Pronoella intermedia* (Moore), *P. sp.*, *Protocardia truncata* (J. de C. Sowerby), *P. sp.*, *Pseudolimea pectinoides* (J. Sowerby), *P. sp.*, *Pseudopecten priscus?* (Schlotheim), *P. sp.*, *?Thracia aequata* Tate, *Echioceras* cf. *typicum* (Trueman and Williams), *E.?*, *Oxynoticeras sp.*, *Paltechioceras aureolum* (Simpson), *P. sp.*, fish fragments.

Lower Lias, zone uncertain, below 194 ft 2 in.

Plant fragments, *Lingula sacculus* Chapuis and Dewalque, *L. sp.*, *Bourguetia?*, *Astarte guexuii* d'Orbigny, *A. sp.*, *Eotrapezium sp.*, *Gervillella hagenowi* (Dunker), *Homomya* cf. *venulithis*, *Liostrea irregularis*, *Modiolus laevis*, *M.* cf. *liasinus* (Terquem), *M. sp.*, *Protocardia philippiana?* (Dunker), *P.* aff. *rhaetica* (Merian), *P. sp.*, *Thracia sp.*, *Euestheria minuta* (Alberti *in* Zieten), *E. sp.*, *Darwinula stricta* T. R. Jones, *Kinkelinella* cf. *acuticostata* (Klinger and Neuweiler), *Gyrolepis?*, *Hybodus* cf. *lawsoni* Duff, *H. sp.*, fish fragments.

Pleistocene and Recent

The mollusca have been identified by Mr. D. K. Kevan and Mr. A. R. Waterston and the foraminifera and ostracoda by Dr. J. R. Haynes and Dr. R. C. Whatley respectively. All the specimens are housed in the Geological Survey Office, Edinburgh.

BURN OF CAIRNFIELD, 230 yd N. 60° E. of Muir of Homie, [42106109]. *Elphidium* cf. *incertum* (Williamson), *E.* cf. *incertum* (near to *Nonion depressulum* var. *asterotuberculatum* Voorthuysen).

CORE BURN, 690 yd E. 2° N. of Parkhill, [43586112]. *Elphidium incertum*, *Protelphidium depressulum* (*sensu* Brady).

EAST MAINS GEOLOGICAL SURVEY BORE, 540 yd N. 21° E. of Gilston, [20446672] at about 3 ft. *Ammonia beccarii* (Linné), *Elphidium excavatum* (Terquem), *Nonion umbilicatulum* (Walker and Jacob), *Hirschmannia viridis* (O. F. Müller), *Leptocythere pellucida* (Baird), *Semicytherura nigrescens* (Baird), *S. striata* (Sars); between 4 ft and 4 ft 6 in *Ammonia beccarii*, *Elphidium crispum* (Linné), *E. excavatum*, *Nonion umbilicatulum*; at about 6 ft *Ammonia beccarii*, *Elphidium excavatum*, *Nonion umbilicatulum*; at about 7 ft *Ammonia beccarii*, *Elphidium excavatum*; at about 11 ft *Ammonia beccarii*, *Elphidum excavatum*; at about 25 ft *Ammonia beccarii*, *Elphidium excavatum*, *Nonion umbilicatulum*, *N. umbilicatulum* (near *Protelphidium depressulum*); at about 51 ft *Cassidulina* cf. *crassa* d'Orbigny, *Protelphidium depressulum*; at about 61 ft *Ammonia beccarii*, ? juv. of *Avrila mirabilis* (Brady); at about 68 ft 6 in *Ammonia beccarii*, *?Elphidium selseyense* (Heron-Allen and Earland), *Nonion umbilicatulum*, *N. umbilicatulum* (near *Protelphidium depressulum*).

LOSSIEMOUTH GEOLOGICAL SURVEY BORE, 900 yd W. 38° N. of Kinneddar, [21586986] at about 2 ft *Protelphidium depressulum*, *Pyrulina sp.*, *Saracenaria sp.*; at about 9 ft *Elphidium selseyense*, *Protelphidium depressulum*; between 16 ft and 17 ft *Buccella frigida* (Cushman), *Buliminella elegantissima* (d'Orbigny), *Cibicides lobatulus* (Walker and Jacob), *Elphidium excavatum*, *E. selseyense*, *Oolina* cf. *melo* (d'Orbigny), *O.* cf. *williamsoni* (Alcock), *Protelphidium depressulum*; at about 22 ft *Cassidulina sp.*, *Elphidium excavatum*, *E. selseyense*; at about 32 ft *Ammonia beccarii*, *Cassidulina* cf. *crassa*, *Cibicides lobatulus*, *Elphidium excavatum*, *E. selseyense*, *?Protelphidium depressulum* (towards *Nonion umbilicatulum*).

REDHILL, exposure 390 yd due S. of Redhill, [16176104]. *Lymnaea sp.*, *Pisidium sp.*

WEST MAINS, exposure 100 yd WNW. of West Mains, [18586633]. Oospores of *Chara sp.* or *Nitella sp.*, *Lymnaea peregra* (Müller). *Physa fontinalis* (Linné), *Planorbis crista* (Linné), *P. laevis* Alder, *Valvata cristata* Müller, *Pisidium milium* Held, *P. nitidum* Jenyns, *P. obtusale* (Lamarck), *Sphaerium corneum* (Linné), Ostracods.

P.J.B.

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Appendix III

GEOPHYSICAL INVESTIGATIONS

BY

P. J. FENNING, B.SC.

WITHIN the last fifteen years the Elgin (95) District has been investigated by various geophysical methods. This account discusses results of regional gravity surveys by several observers on both land and sea areas within the district. In 1963 the Geophysics Department of the Geological Survey investigated regional variations in both gravity and total magnetic force throughout the land area. Detailed gravity and magnetic traverses were carried out to define in detail anomalous areas revealed by the regional surveys. Later an aeromagnetic survey was flown over the whole district and indicated a positive magnetic feature trending north-south and passing roughly 5 miles east of Elgin.

Interpretations of detailed gravity and seismic refraction traverses across the Loch Spynie basin indicated a channel filled with low-density material lying within the superficial deposits, which appeared to be about 100 ft thick. A site for a borehole was thereupon selected to obtain a representative succession of these deposits (p. 132).

Results of laboratory measurements of physical properties of rock samples collected from the district are also presented.

REGIONAL GRAVITY SURVEYS

The first gravity survey within the Elgin District was carried out by W. Bullerwell and J. Phemister (personal communication) who observed eleven gravity stations in this area during 1953. B. J. Collette (1960) gave an account of underwater gravity observations surveyed in the Moray Firth with a remote-controlled North American gravity meter in October 1957. Three of these underwater gravity stations were located in the off-shore area within the area of the Elgin (95) Sheet. The results of this survey demonstrated the existence of a large negative gravity anomaly in the Moray Firth flanked to the south-east by positive anomalies near the Banffshire coast. The negative anomaly was explained by Collette in terms of a large granitic batholith at shallow depth.

During August 1963, the Geophysics Department of the Geological Survey conducted a regional gravity survey over the whole land area of the Elgin (95) Sheet and its immediate surroundings. Using two Worden gravity meters, observations were made at 422 stations, of which 268 were located within the Elgin District, maintaining a station distribution of about two per square mile. Gravity values were referred to a datum of 981·265 cm/s^2 at Pendulum House, Cambridge, through acceptance of a value of +446·17 milligals at a gravity base station in Elgin. In addition, other base stations were occupied at Kinloss [06346164] and Cullen [51246713], all bases having been linked into the main British network during 1961 by R. McQuillin (*Sum. Prog. Geol. Surv.* for 1961, 1962, p. 64). Gravity data were reduced to sea-level using the following mean densities for the district based on laboratory determinations which are discussed below.

Drift, Jurassic, Permo-Triassic and Old Red Sandstone . 2·40 g/cm^3
Moinian and Dalradian . . .. 2·70 g/cm^3

The Bouguer anomaly at each station was corrected for the gravitational effect of irregular topograpby surrounding the station, using a graticule method developed by Hammer (1939). Resulting Bouguer anomalies represent departures from the theoretical gravity of tbe International Gravity Formula of 1930 and have been plotted and contoured on a map on a scale of one inch to one mile which is reproduced at a reduced scale as Plate VA. For completeness, relevant underwater gravity stations of Collette's 1957 survey have been converted to Bouguer anomalies which are incorporated in tbe map; the station reference number used in Collette (1960) is enclosed in brackets.

The Bouguer anomaly map shows that the highest gravity values occur in the east of the district where Dalradian rocks crop out south-east of Buckie, a value of —(minus) 3 milligals being recorded half a mile south of Newton of Letterfourie [43836078]. Westwards there is a sharp decrease in gravity with contours trending north-east across the Dalradian–Middle Old Red Sandstone boundary and a steady decrease in gravity values across the Middle and Upper Old Red Sandstone towards Elgin. A similar gravity change northwards across the Old Red Sandstone deposits may be noted soutb of Elgin but the dominant contour trend is east–west. Westwards this trend is interrupted by a positive gravity axis aligned north-east from Morayscairn [10606092] through Quarrywood [18176412] to Locbside [20726559]. This positive gravity feature is flanked by subsidiary negative features, the southerly gravity low extending from Forresterseat [15855811] through Elgin to Speyslaw [28456682] while the northerly feature extends from one mile north of Kinloss through Easter Coltfield [12006444] to Gordonstoun [18436900]. Along the southern shore of Findhorn Bay to the College of Roseisle [13766651] is a prominent positive anomaly, aligned east–west, with a maximum closure of —(minus) 14 milligals centred at Wards [12176556].

It is noteworthy that the Bouguer anomalies of Bullerwell and Phemister agree well with those observed by the Geophysics Department.

Density Estimates. A suite of rock samples was collected from surface exposures and Geological Survey boreholes in the Elgin District and the saturated, dry and grain densities and also the effective porosity of 42 specimens were determined in the Geophysics Laboratory by Mr. H. Rutter. The results are summarized in Table V.

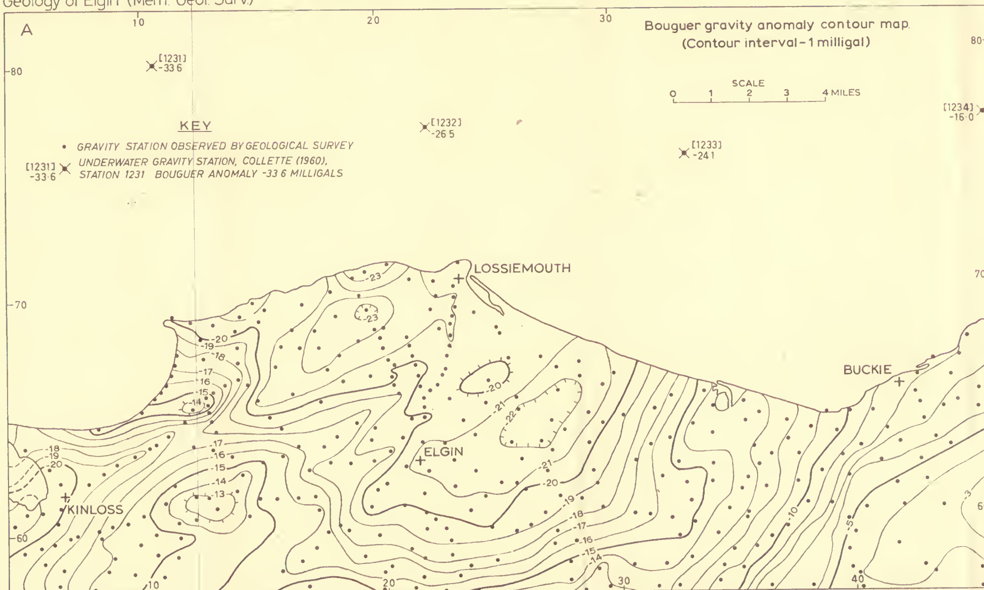
A comparison of the saturated densities listed in Table V shows that there is a density contrast of approximately 0·20 g/cm^3 between Dalradian rocks, with a mean saturated density of between 2·63 and 2·76 g/cm^3, and rocks of the Middle Old Red Sandstone Series, with a mean saturated density varying from 2·47 to 2·54 g/cm^3. An even larger density contrast of perhaps 0·40 g/cm^3 is likely between Upper Old Red Sandstone strata and Dalradian rocks. The difference in saturated density between Middle Old Red Sandstone and Upper Old Red Sandstone appears to be mainly due to the much higber porosity values of the latter. However, for the reduction and interpretation of gravity data, saturated density values of 2·70 g/cm³ and 2·40 g/cm³ have been adopted for Dalradian and both Middle and Upper Old Red Sandstone respectively.

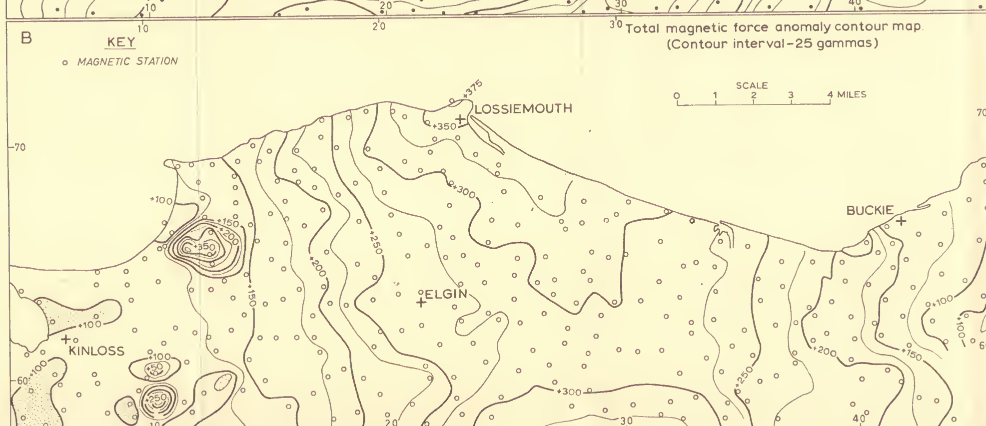
TABLE V

Rock Group	No. of Specimens	No. of Localities	Mean Density (g/cm³)			Effective Porosity %
			Saturated	Dry	Grain	
Jurassic sandstone	1	1	2·40	2·26	2·64	14
Jurassic mudstone	1	1	2·23	1·96	2·70	27
Triassic						
Cherty Rock	2	1	2·62	2·60	2·65	2
Upper Triassic sandstone	7	2	2·49	2·40	2·62	9
Burghead sandstone	1	1	2·58	2·52	2·67	6
Permian sandstone	1	1	2·34	2·11	2·64	23
Upper O.R.S.						
Sandstone	8	3	2·30	2·09	2·65	21
Mudstone	2	1	2·24	2·01	2·63	23
Conglomerate	3	1	2·34	2·21	2·54	13
Middle O.R.S.						
Sandstone	3	2	2·47	2·33	2·71	14
Conglomerate	1	1	2·54	2·46	2·66	8
Dalradian						
Cairnfield Flags	5	5	2·76	2·74	2·79	2
Findlater Flags	4	4	2·77	2·75	2·81	2
Cullen Quartzite	3	3	2·63	2·61	2·65	2

The Upper Triassic strata exhibit higher saturated densities than the Jurassic, uppermost Permian and Upper Old Red Sandstone strata and it may prove feasible to delineate areas of Upper Triassic strata, if sufficiently thick, by detailed gravity traverses.

Gravity Interpretation. In the eastern part of the Elgin District there is a sharp change in gravity gradient across the Dalradian–Middle Old Red Sandstone junction with a maximum gradient of 5 mgal/mile located half a mile west of Clochan [40206090]. South of Garmouth [33926445] the gravity gradient decreases across the Middle Old Red Sandstone–Upper Old Red Sandstone junction before increasing sharply across the less dense Upper Old Red Sandstone deposits and then flattening out in the direction of Duffus [17086867]. The thicknesses of Middle and Upper Old Red Sandstone strata are difficult to assess in the eastern half of the district because of difficulties in extrapolating a regional gravity gradient which exists across the area of exposed Dalradian rocks. Additional gravity stations were surveyed along the A98 road from


A
Bouguer gravity anomaly contour map.
(Contour interval - 1 milligal)
SCALE
0 1 2 3 4 MILES
KEY
• GRAVITY STATION OBSERVED BY GEOLOGICAL SURVEY
[1231] -33·6 UNDERWATER GRAVITY STATION, COLLETTE (1960), STATION 1231 BOUGUER ANOMALY -33·6 MILLIGALS
[1231] -33·6
[1232] -26·5
[1233] -24·1
[1234] -16·0
LOSSIEMOUTH
BUCKIE
ELGIN
KINLOSS


B
KEY
o MAGNETIC STATION
Total magnetic force anomaly contour map.
(Contour interval - 25 gammas)
SCALE
0 1 2 3 4 MILES
LOSSIEMOUTH
BUCKIE
ELGIN
KINLOSS

Rathven [44306570] to Portsoy in order to assess tbis background field but results were complex, indicating a pronounced gravity increase eastwards between Cullen and Portsoy. No simple representation of the regional field across the Dalradian rocks could be extrapolated into the Elgin District for the purpose of assessing the gravity field solely due to Old Red Sandstone deposits. However, from an examination of the observed gravity field in the south of the district and of several gravity stations observed by Bullerwell and Phemister between Elgin and Rothes, it appears that the east–west gradient here is associated directly with the Moinian–Old Red Sandstone junction and it is suggested that an anomaly of at least 10 milligals is attributable to a northward increase in the thickness of Old Red Sandstone deposits. Noting that the average gravity gradient between Brown Muir [25845514] and Greens of Coxton [25206093] is 2·5 milligals per mile and assuming a density contrast of 0·30 g/cm^3 between Moinian and Old Red Sandstone deposits, then, according to Jakosky (1950, p. 359) the dip of the interface between Moinian and Old Red Sandstone is 7 degrees northwards. On this basis the tbickness of Old Red Sandstone deposits one mile west of Elgin, where the gravity gradient bas slackened, is about 2500 ft.

The positive axis aligned north-east from Morayscairn to Lochside is probably associated with an extension of fairly dense Moinian rocks beneath a relatively thin cover of Old Red Sandstone and later deposits.

In order to delineate the positive gravity feature located along the southern shore of Findhorn Bay, a detailed gravity traverse, with stations at 100-yd intervals, was surveyed from North Alves [12316331] to Burghead across the maximum gravity closure at Wards. The observed gravity profile G 1 on Fig. 19(a) exhibits a positive gravity anomaly of 5 mgal superimposed on a background field which is steadily decreasing northwards. Removal of tbis background field results in a residual positive anomaly of 5·2 mgal as sbown on Fig. 19(b) with the maximum located 150 yd west of Wards. It is suggested that this residual anomaly can be resolved into two separate components. The first component is a distinct change in Bouguer anomaly level of +3·3 mgal which is evident from a comparison of the first fifteen and the last twenty stations on the residual profile. This change in Bouguer anomaly level may be attributed to a density contrast across a steeply dipping junction or fault located along the southern margin of Findhorn Bay. From a study of tbe saturated densities in Table V it is suggested that the density contrast arises between metamorphic rocks to the north and less dense Old Red Sandstone strata to the south. The second component of the residual anomaly is an asymmetrical positive gravity anomaly of 2 mgal located between stations 20 and 42. Also plotted on the same horizontal scale as the residual gravity profile in Fig. 19(b) is a total force magnetic profile defining a positive magnetic anomaly of more than 300 gammas coincident with this asymmetrical gravity anomaly. The details and results of the magnetic surveys are discussed in a later section, but from the coincidence of these two geophysical anomalies a likely explanation may be the presence of an igneous body, of limited areal extent, located within the Dalradian or Moinian. Because of the inherent impossibility of separating these two residual gravity effects, no reliable quantitative conclusions could be drawn. In spite of the possibility of a density contrast between Triassic strata and other sedimentary formations, no firm conclusions on the distribution of Triassic strata within the Elgin District could be drawn from the regional and

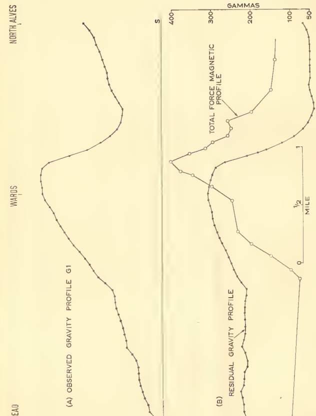


FIG. 19. (a) *Bouguer anomaly profile across Wards anomaly*
(b) *Residual Bouguer anomaly and total force magnetic profiles across Wards anomaly*

detailed gravity surveys. However, it is noteworthy that the Jurassic strata encountered in the Lossiemouth Borehole are within the northerly negative gravity feature extending from Kinloss to Gordonstoun.

If the steep gravity gradients discovered by Collette on the southern edge of the Moray Firth negative anomaly are extrapolated into the area of the land gravity survey there is reasonable agreement in gravity contour trend and values between the two surveys. From an interpretation of the gravity gradients Collette (1960, p. 14) has suggested that a body with a thickness of at least 10 km and a density contrast of 0·30 g/cm^3 is required to produce this negative gravity anomaly and states: 'Although a thin sedimentary cover may be present it cannot reach this dimension. We thus come to the hypothesis of a non-exposed shallow-seated granitic batholith'. However, from a study of saturated rock densities it has already been suggested that a density contrast of 0·30 g/cm^3 between Dalradian rocks and both Middle and Upper Old Red Sandstone strata is plausible. Assuming a density for granite of between 2·60 and 2·70 g/cm^3, which is reasonable in the light of measurements reported by Bott (1953, p. 260), then the density contrast between Dalradian rocks and granite would probably be of the order of 0·1 g/cm^3. Doubtless rocks of higher density than the measured Dalradian samples exist within the region, for example, the igneous mass west of Portsoy, in which case the density contrast between this denser material and the Old Red Sandstone is in excess of 0·3 g/cm^3 and thus a smaller thickness of Old Red Sandstone and perhaps later deposits would be required to account for the Moray Firth negative anomaly. From a consideration of the steep gravity gradients associated with the Dalradian–Old Red Sandstone junction in the Elgin District and the possible density contrasts involved, it is at least equally possible that the Moray Firth negative gravity anomaly could be due to a basin of Old Red Sandstone, probably together with later deposits, as to a granite batholith.

Donovan (1963) states that the postulate by Collette of a granite in the Moray Firth is geologically unconvincing and, noting the narrow strips of Mesozoic rocks outcropping along the shores of the Moray Firth and the presence of the Helmsdale Boulder Bed, he suggests that the gravity anomaly is due to a Mesozoic basin with faulted margins lying close to the present shores. Hallam (*in* Craig 1965) also prefers a major basin of Mesozoic sediments rather than a granite within the Moray Firth.

Magnetic Surveys

It is of historical interest that Sir Edward Sabine (1870) recorded an observation of magnetic declination and inclination made at Elgin in 1857 by J. Welsh. During a later magnetic survey of the British Isles Rücker and Thorpe (1890) made observations of declination, inclination and horizontal force in 1885 at a station in Elgin. In 1915 G. W. Walker (1919) occupied another station at Elgin in the course of a resurvey of the main magnetic features of the British Isles obtained earlier by Rücker and Thorpe. Walker reduced his observations of horizontal force, inclination and declination to epoch 1st January 1915.

As part of a survey to assess secular variation changes in the magnetic elements and also derive a simple expression for the regional variation of the main geomagnetic field in Great Britain, members of the Geophysics Department of the Geological Survey reoccupied Walker's Elgin magnetic station in

1955, 1963 and 1964. The observations were reduced to epochs 1956·0 and 1963·5 respectively. A comparison of tbe various observations at this Elgin magnetic station shows that as a result of secular variation the total magnetic force decreased from a value of 49 101 gammas at epoch 1915 to 49 016 gammas at epoch 1956, but at epoch 1963·5 the value had increased to 49 239 gammas.

A total force ground magnetometer survey, comprising 400 observations, was conducted simultaneously with the regional gravity survey throughout the Elgin District and environs by the Geophysics Department of the Geological Survey. All magnetic observations were made using proton magnetometers and corrected for both diurnal and geomagnetic variations. The diurnal variations of the magnetic field were corrected assuming a linear drift between readings at a base station in Elgin which was reoccupied at about four-hourly intervals. The correction employed for regional geomagnetic variation was computed for epoch 1955·5 from magnetic observations at 26 observation points located throughout Great Britain and entails the removal during data reduction of +2·1728 gammas/km to National Grid North and +0·259 gammas/km to National Grid West. The corrected total force values were referred to an arbitrary value of 49 230 gammas at the Elgin base station and the final values are presented as a contour map with a contour interval of 25 gammas (Plate VB).

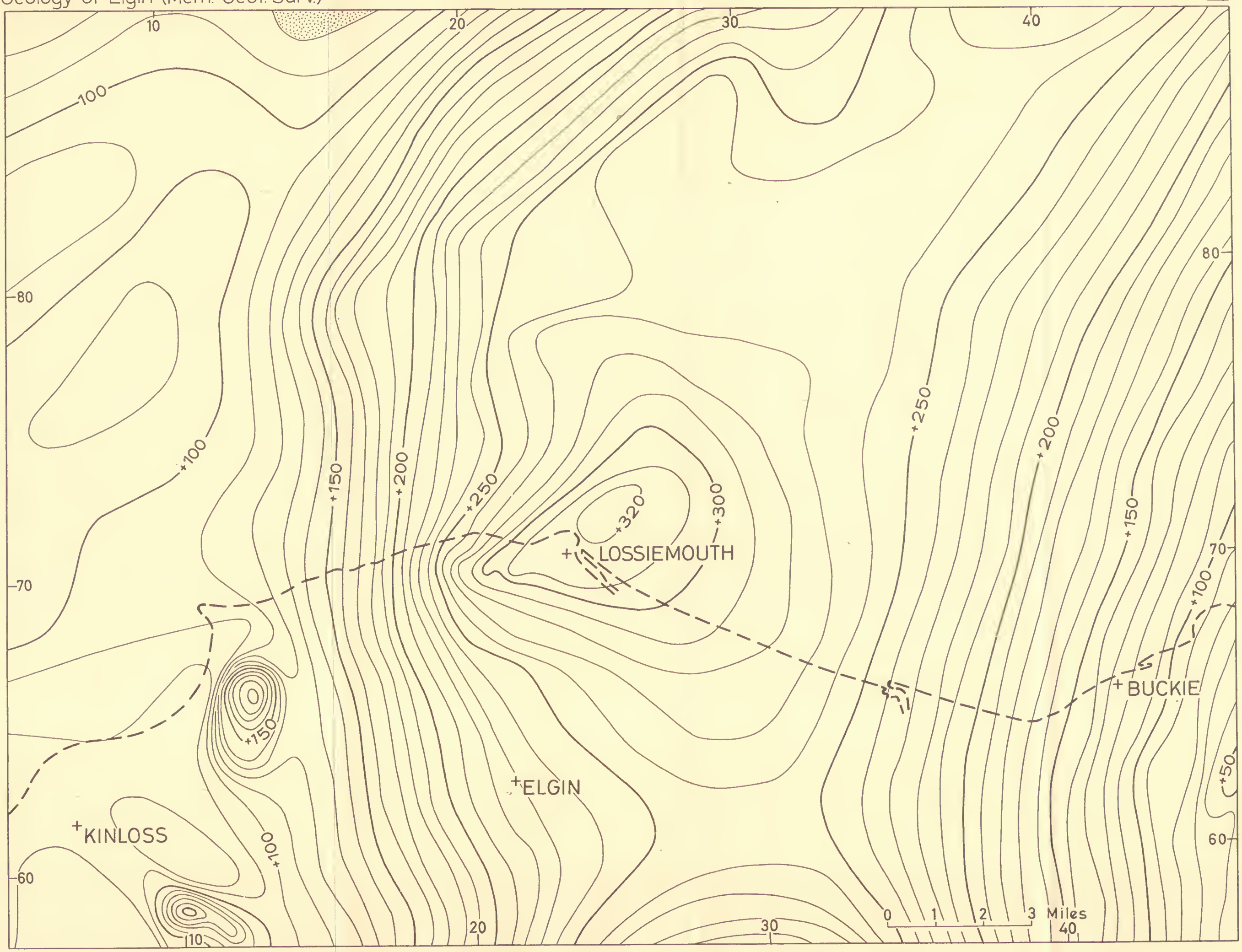
Total force values show little correlation with surface geology. Magnetic values increase from both east and west indicating a positive magnetic feature trending north–south through Urquhart [28656268] but maximum values are located slightly westwards at Lossiemouth. Two small local positive anomalies have been delineated at Wards and south of Brodieshill [10005988], the latter anomaly exhibiting an associated negative anomaly on the northern margin. As previously stated (p. 143), the positive magnetic anomaly at Wards has an amplitude of 300 gammas and is coincident with a pronounced positive gravity anomaly. A compilation of the regional magnetic survey and two detailed traverses surveyed across the Wards anomaly indicates a small negative anomaly to the north of the positive feature and for interpretation purposes this is taken to indicate induced magnetization solely. A similar assumption is made in the case of the Brodieshill magnetic anomaly.

Interpretation of the Wards anomaly was effected using an approximate method due to Peters (1949) and suggested that the depth to the top of a vertical slab of infinite depth extent and anomalous magnetization varies from 950–1250 ft. The casual body is interpreted as an igneous mass, probably situated within the Pre-Cambrian.

The anomaly south of Brodieshill exhibits a peak to peak amplitude of 250 gammas but unfortunately this anomaly was not investigated by detailed magnetic traverses. However, from the anomaly location, which is on tbe edge of the Moinian outcrop and within an area of positive gravity anomaly, the most probable explanation is an igneous mass within the Moinian rocks.

Unfortunately no susceptibility values have been determined for the rocks exposed within the Elgin District but it is thought unlikely that any major susceptibility contrasts exist within the exposed sedimentary rocks.

Aeromagnetic Survey. During 1964 a total force aeromagnetic survey was flown over the Elgin District, including off-shore areas, as part of a regional aeromagnetic survey carried out in North Scotland by Hunting Surveys, Ltd.,



Total force aeromagnetic contour map. (Contour interval - 10 gammas) under contract to the Geological Survey. Using a fluxgate magnetometer, variations in the Earth's total magnetic field were recorded along east–west National Grid lines at 2 km intervals and at a flight height of 1000 ft above terrain. Additional tie lines were flown at 10 km intervals along north–south National Grid lines. Aeromagnetic total field anomalies shown in Plate VI, with a contour interval of 10 gammas, represent deviations from a linear geomagnetic field computed hy the same procedure as used in the reduction of the ground magnetic surveys.

The aeromagnetic anomaly contour map exhihits a large positive magnetic axis with a maximum enclosure located one mile east of Lossiemouth. To the north of this feature the axial trend changes from north–south to north-east–south-west. There is good correspondence between the aeromagnetic anomaly map (Plate VI) and the ground magnetic map (Plate VB) with the exception of the Brodieshill anomaly, which is shown as trending north-west on the aeromagnetic map in contrast to the circular enclosure delineated hy the ground magnetic survey. One explanation of this discrepancy hetween the two surveys is that the recorded values of certain ground magnetic stations may have heen affected by local artificial disturbances or a magentic storm which occurred in an interval hetween magnetic hase readings.

An approximate interpretation method developed by Smellie (1956) has heen applied to an aeromagnetic profile across the Brodieshill anomaly. The most satisfactory interpretation is achieved hy representing the causal hody by a line of magnetic poles striking at N. 40° E., in which case the estimated depth is 1100 ft helow ground surface. Another interpretation in terms of a two dimensional body gives a depth helow ground surface of 1600 ft.

Aeromagnetically the positive feature at Wards is defined as a symmetrical enclosure slightly elongated along a north–south axis, which is in contrast to the roughly east–west elongation of the crescent-shaped maximum anomaly indicated hy the ground magnetic survey. Application of the methods of Peters and Smellie to the aeromagnetic anomaly near Wards gives depths below ground surface to the top of the causal magnetic hody of 2300 ft and 3100 ft respectively, which compare unfavourahly with depths varying from 950–1250 ft interpreted from ground magnetic data. However, one explanation may be that the aeromagnetic flight line spacing is large compared with the area of the Wards anomaly and is probably insufficient to define the anomaly accurately for interpretation purposes.

Geophysical Surveys Across the Loch Spynie Basin

Consequent on the regional gravity and ground magnetic surveys ohserved in the Elgin District hy the Geophysics Department of the Geological Survey, a series of detailed gravity, seismic refraction and resistivity observations were made north of Elgin across the hasin of the former Loch Spynie. The object was to obtain information concerning the configuration of superficial deposits and therehy assist in the selection of a site for an exploratory bore.

Inspection of the Bouguer anomaly map (Plate VA) for evidence of a negative anomaly in the Loch Spynie area, caused hy a basin of superficial deposits within consolidated strata, proved fruitless. However, two hundred additional gravity stations were surveyed along four north–south traverses located across the Loch Spynie basin. The positions of the traverses and the observed Bouguer anomaly profiles are given in Figs. 20 and 21 respectively.

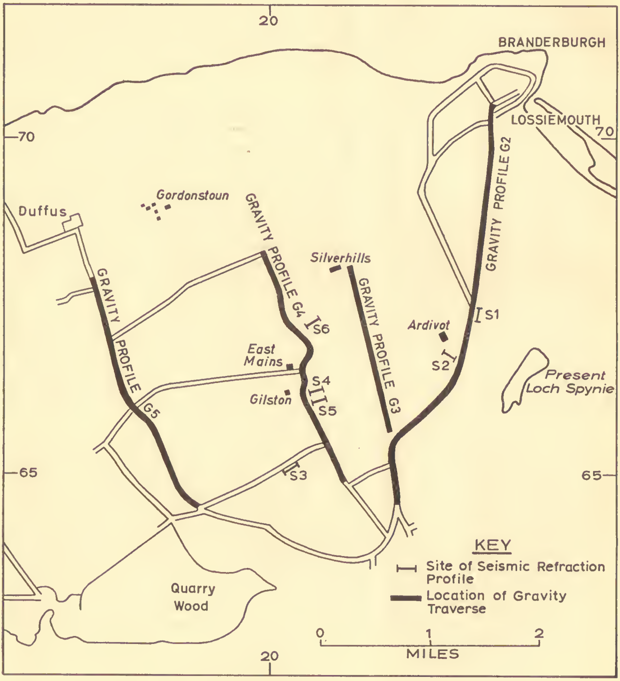


FIG. 20. *Sketch map showing location of gravity and seismic refraction profiles across Loch Spynie basin*

It can be seen that gravity profile G3, situated between a point [21756565] and Silverhills [20906808], and gravity profile G4, observed along the road between Myreside [21566492] and a point [19816842) both exhibit a small negative anomaly superimposed upon the northern gradient of the positive gravity axis which extends through Quarry Wood to Lochside. This northern regional gradient is well defined by gravity profile G5, extending a half-mile east of Loanhead [18376453] to Phillexdale [16836787]. If the regional gravity gradient is removed from profiles G3 and G4 by inspection, the residual anomaly is a gravity trough of about 0·5 mgal situated on profile G4 between stations 10

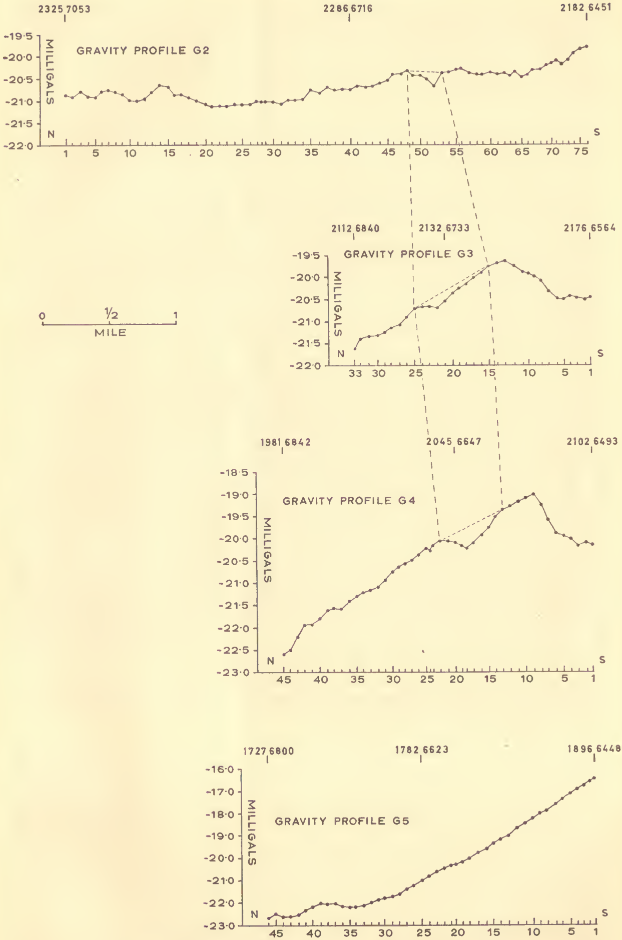


FIG. 21. *Gravity profiles across Loch Spynie basin*

and 22, and on profile G3 between stations 15 and 25. This residual gravity trough is asymmetrically disposed to the boundaries of Loch Spynie as indicated by the geological mapping, since on profile G4 it overlaps the southern boundary, whereas on profile G3 it is situated within the northern part of the basin. Gravity profile 2 differs in regional field from the three gravity profiles already mentioned, but inspection suggests a pronounced negative anomaly between stations 48 and 53 and this anomaly coincides witbin the postulated limits of the basin. Between stations 15 and 46 on profile G2 there is another negative anomaly which may be attributed to alluvial deposits of the River Lossie.

Borehole evidence and the results of seismic refraction surveys, which are discussed below, suggest appreciable thicknesses of superficial deposits outside the postulated boundaries of the Loch Spynie basin and thus the negative gravity anomaly across Loch Spynie will not be simply that of an alluvial basin bounded by consolidated strata. From the positions of the gravity trough witb respect to the boundaries of the Loch Spynie basin the gravity trough has been interpreted as a channel cut witbin the superficial deposits and filled with low density material. Hall and Hajnal (1962) concluded from a gravity meter study of buried valleys in Saskatchewan that 'filled glacial valleys which are cut entirely into drift, or partly into drift and partly into bedrock can have sufficient density contrast to give rise to measurable gravity anomalies'. From studies of borehole samples the authors suggest the densities of alluvial deposits range from silt of density 1·80 g/cm³ to till of density 2·20 g/cm³.

Unfortunately there is no surface indication of a low density channel and this precludes accurate interpretation of the residual negative anomaly, which entails a knowledge of the boundaries of the causal body, but approximate interpretation using a two-dimensional graticule method developed by Heiland (1940) has been attempted. Assuming a density contrast of 0·30 g/cm³ between the low density material in the infilled channel and the adjacent strata and superficial deposits, then the gravity anomaly due to a rectangular trough, 120 ft in depth and 1400 ft wide, situated between stations 15 and 20 on gravity profile 4 is in reasonable agreement with the residual gravity anomaly derived from gravity profile 4. Calculated gravity anomalies for a V-shaped trough of similar width do not correspond well with the residual anomaly but the anomalies caused by a wider V-shaped trough would probably ensure a better correspondence. No density measurements of superficial deposits were carried out owing to difficulties in obtaining representative samples and in determining the density of unconsolidated deposits.

Seismic Refraction Surveys. Six seismic refraction traverses were surveyed in and around the Loch Spynie basin to provide additional control for interpretation of gravity results. The positions of these six refraction traverses, S_1–S_6, are indicated in Fig. 19. In this refraction work an engineering seismograph, model Fs–2 manufactured by Hunting Survey Corporation, which entails tbe production of seismic waves by a hammer blow, was used. Under ideal conditions with this equipment the maximum separation between shock point and detector is of the order of 400 ft, but in the Loch Spynie area noise from low-flying aircraft frequently confused results.

Four seismic traverses were observed in the vicinity of gravity traverse 3. Seismic traverses S4 and S5 were situated over the position of the gravity trough but on opposite sides of the clay pit located 300 yd SE. of Gilston [20266624].

Results of traverse S4 indicate about 90 ft of a layer with a velocity 5500 ft/s, interpreted as superficial deposits, overlying a layer of velocity 9200 ft/s, interpreted as bedrock. Seismic traverse S5 indicates a layer of velocity 5000 ft/s but no refracted arrivals from bedrock were obtained. Assuming a bedrock velocity of 10 000 ft/s the minimum thickness of low velocity drift at this location must be 110 ft.

Seismic traverse S6 was sited 150 yd S. of Salterhill [20486729]. Once again no refracted arrivals from bedrock were obtained and a minimum thickness of 110 ft of a layer with velocity 5000 ft/s was inferred, assuming a bedrock velocity of 10 000 ft/s. The northern edge of Findrassie Wood [20536536] was the site of seismic traverse S_3 and although the traverse is only 600 ft north of quarries exposing Upper Triassic sandstone the seismic results indicate a 10-ft layer of velocity 1000 ft/s (probably top-soil or loose sand) overlying at least 50 ft of material with a velocity of 7100 ft/s. This latter velocity is higher than those previously recorded for superficial deposits but is taken to be indicative of these deposits on the basis of laboratory tests carried out on dry samples of Upper Triassic Sandstone from the Elgin District. The results of these tests, which are described later, show that in the laboratory the compressional wave velocity of Upper Triassic sandstone varied from 10 500–17 700 ft/s.

Two other seismic refraction traverses, S_1 and S_2, were surveyed in the vicinity of gravity traverse 1. Seismic traverse S_1, located at the junction of A941 Elgin to Lossiemouth road and the lane to Ardivot [22636706], indicated 43 ft of a low velocity layer (4100 ft/s) overlying another layer of minimum thickness 30 ft and velocity 6250 ft/s. Both velocities are considered to be typical of superficial deposits. Seismic traverse S_2, observed 1/3rd-mile SSE. of Ardivot, indicated a low velocity layer (5600 ft/s) of minimum thickness 83 ft.

Laboratory Seismic Investigations. In an attempt to correlate seismic velocities with characteristic rock types, the compressional wave velocities of eleven dry rock samples from the Elgin District were determined in the laboratory. The rock samples were held under slight uniaxial load and the compressional wave velocities, determined by a pulse method using a Cawkell Ultrasonic Materials Tester, are given below:

Rock Group	No. of Specimens	No. of Localities	Range of compressional wave velocity (Ft/s)	Mean compressional wave velocity
Cherty Rock	2	1	14120–17980	16070
Upper Triassic sandstone	6	2	10550–17740	14830
Burghead sandstone	1	1	10240	10240
Hopeman sandstone	2	1	8680–12210	10040

No samples of Old Red Sandstone were available for velocity determination but with this omission in mind it can be seen from the above that the level of velocities is generally higher than those recorded at seismic traverses S_1–S_6. One exception is the material interpreted at S_4 as bedrock with a velocity of 9200 ft/s which is within the range of seismic velocities determined for two Hopeman sandstone specimens collected at Covesea [18327098].

It is important to note that the laboratory velocity determinations were made on dry samples and, because rocks *in situ* are usually water-saturated, the effect of water saturation upon rock velocity must be considered. Koefoed, Oosterveld and Alons (1963) concluded from a survey of relevant literature combined with laboratory measurements on limestone using a low frequency pulse method, that water saturation results in a decrease of velocity at low frequencies and an increase of velocity at high frequencies. Thus it is apparent that the velocity of water-saturated rock changes appreciably with frequency and this should be considered when comparing velocity values determined by the laboratory pulse method with velocity values obtained by field seismic refraction surveys. However, in the interpretation of the seismic refraction surveys carried out in the Elgin District, velocities varying between 5000 and 7100 ft/s were considered to be representative of superficial deposits.

Selection of a Borehole Site. A site for a borehole which was drilled through the Loch Spynie basin was selected on geophysical evidence. It was important that this borehole should be sited where the superficial deposits are thickest and most likely to be fully represented. Evaluation of seismic refraction results indicated that superficial deposits, at least 100 ft thick, are to be found in the vicinity of the clay pits at Gilston [20266624]. However, gravity interpretation suggested that this location is situated on a channel of low-density material within the superficial deposits. On the northern margin of the Loch Spynie basin, 150 yd S. of Salterhill [20486729], the superficial deposits were estimated to have a minimum thickness of 110 ft, and it was suggested that a borehole sited there or between that locality and the northern limit of the gravity trough [20436664] on gravity profile 3 would encounter a more representative succession of superficial deposits than a borehole sited over the low density material of the infilled channel.

A borehole was sited north-east of East Mains at [20436671], outside the postulated northern limit of the low-density channel, and encountered 107 ft of superficial deposits overlying Old Red Sandstone. P.J.F.

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Appendix IV

LIST OF GEOLOGICAL SURVEY PHOTOGRAPHS

Taken by Messrs. W. D. Fisher and R. Lunn

Copies of these photographs are deposited for public reference in the library of the Institute of Geological Sciences, South Kensington, London, S.W.7, and in the library of the Institute of Geological Sciences, 19 Grange Terrace, Edinburgh, 9. Prints and laotern slides are supplied at a fixed tariff on application to the Director.

Pleistocene and Recent

C 1467–9	Gravel ridges representing storm-beaches on raised beach; Lossiemouth. mouth.
1476–7	Deserted sea-cliffs at edge of raised beach; 4 miles W. of Lossiemouth.
D 605	Terrace gravel on Old Red Sandstone; near Fochabers Bridge.
606	Glacial sand and gravel; Gollachy Croft.
607	Glacial channel; Slackhead.
608	Post-Glacial beach and cliff; Auchenreath.
609	Fluvio-glacial terrace; Burn of Tynet.
677–8	Quarries in beach-shingle; ½-mile S. of Lossiemouth.
680–4	Shingle-ridges of post-Glacial beach; Caysbriggs and Covesea.
689–91	Glacial striae, late-Glacial beach gravels, and till; Greeobrae Quarry, Hopeman.
698	Glacial gravel and sand overlying red till; quarry near Duffus.
699	Feature and flat of raised beach; Hopemao.
702–4	Old sea-cliff in glacial deposits; Ardivot.
713–4	Terrace feature; south of Quarry Wood.
718–23	Features of glacial sands and silts; Hempriggs Saodpits.
724	Raised beach; NNE. of Milton Brodie House.
725	Ridge of glacial sand and gravel; Hempriggs.
726–7	Glacial sand and gravel overlying till; Morayscairn.
728–9	Fluvio-glacial features; Black Burn valley.
730	Glacial chainage chaonel; Burgie Lodge Farm.
734–5	Gravel pit; Craoloch.
736–8	Lesmurdie sand-pit.
D 739–40	Fluvio-glacial terraces; Kirkhill Wood and Castle Hill.
742–44	Glacial meltwater channels; Glenlossie and Blackhills.

Permian and Triassic

C 1470–80	Hopeman sandstone; shore near Covesea.
1481–2	Cutties Hillock sandstone; Quarry Wood.
679	Caves and stacks in Hopeman sandstone; Gow's Castle, Covesea.
685–6	Contorted beddiog io Hopeman sandstone; Covesea.
687–8	Concretionary sandstooe in Hopeman sandstone; near Greenbrae Quarry.
691–2	Hopemao sandstone; Greenbrae Quarry.
693	Fluorspar nodules in concretionary saodstone; near Greenbrae Quarry.
694–5	Contorted bedding in Hopeman sandstone; near Covesea.
696	Burghead Bed; Burghead.
697	Faulted contact between Burghead Beds and Hopeman sandstone; ocar Burghead.

700	Faulted contact of Upper Old Red Sandstone and Triassic; Lossiemouth.
701	Cherty Rock; Lossiemouth.
709–11	Cuttie's Hillock sandstone; Rosebrae Quarry.
712	Quarries in Cuttie's Hillock sandstone; Quarry Wood.

UPPER OLD RED SANDSTONE

D 705–8	Sedimentary structures in Rosebrae Beds; Quarry Wood and Knock of Alves.

MIDDLE OLD RED SANDSTONE

D 601	Basal breccia resting on Cullen Quatzite; Burn of Buckie.
602–3	Limestone with angular quartzite fragments (Buckie Beds) resting on Cullen Quartzite; shore, near Buckie.
604	Flaggy red sandstone and siltstone with calcareous nodules below upper Fish Bed of Tynet; Burn of Tynet, near Lower Mills of Tynet.

DALRADIAN

D 596–9	Cullen Quartzite showing sedimentary features; shore, Portessie.
600	Recumbent folding in Cairnfield Actinolitic Flags; Burn of Tynet, near Nether Allaloth.

MOINIAN

D 715–7	Recumbent folds, foliation and jointing in psammitic granulite; Wester Newforres Old Quarry.

INDEX

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